

VISUALIZATION IN

Alyssa A. Goodman

Harvard-Smithsonian Center for Astrophysics
Radcliffe Institute for Advanced Study

@AlyssaAGoodman

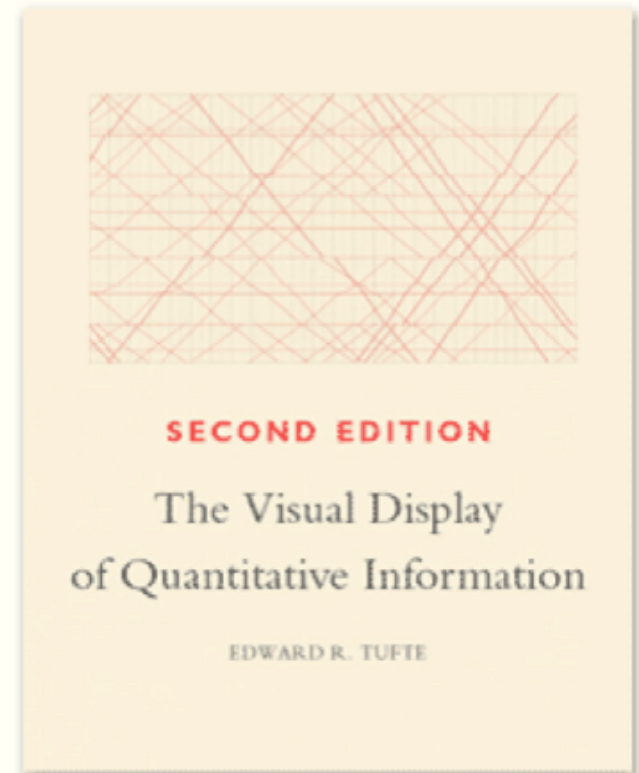
VISUALIZATION IN



THE VISUAL DISPLAY OF QUANTITATIVE INFORMATION

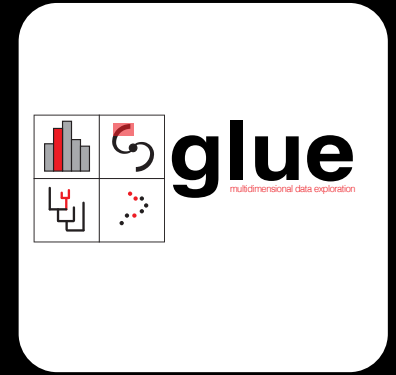
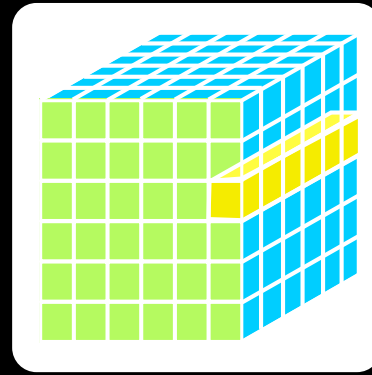
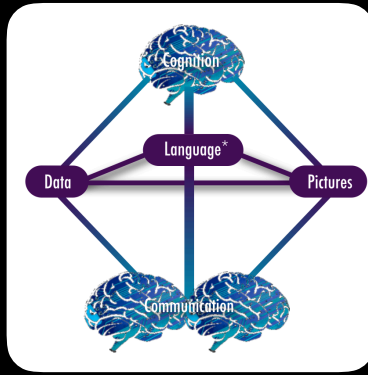
The classic book on statistical graphics, charts, tables. Theory and practice in the design of data graphics, 250 illustrations of the best (and a few of the worst) statistical graphics, with detailed analysis of how to display data for precise, effective, quick analysis. Design of the high-resolution displays, small multiples. Editing and improving graphics. The data-ink ratio. Time-series, relational graphics, data maps, multivariate designs. Detection of graphical deception: design variation vs. data variation. Sources of deception. Aesthetics and data graphical displays.

This is the second edition of *The Visual Display of Quantitative Information*. Recently published, this new edition provides excellent color reproductions of the many graphics of William Playfair, adds color to other images, and includes all the changes and corrections accumulated during 17 printings of the first edition.



(READ CANON LAW)

VISUALIZATION IN



(LIVING BY THE CANON IN 2019)



TEN QUESTIONS TO ASK WHEN CREATING A VISUALIZATION

The 10 Questions

1. **Who** | Who is your audience? How expert will they be about the subject and/or display conventions?
2. **Explore-Explain** | Is your goal to explore, document, or explain your data or ideas, or a combination of these?
3. **Categories** | Do you want to show or explore pre-existing, known, human-interpretable, categories?
4. **Patterns** | Do you want to identify new, previously unknown or undefined patterns?
5. **Predictions & Uncertainty** | Are you making a comparison between data and/or predictions? Is representing uncertainty a concern?
6. **Dimensions** | What is the intrinsic number of dimensions (not necessarily spatial) in your data, and how many do you want to show at once?
7. **Abstraction & Accuracy** | Do you need to show all the data, or is summary or abstraction OK?
8. **Context & Scale** | Can you, and do you want to, put the data into a standard frame of reference, coordinate system, or show scale(s)?
9. **Metadata** | Do you need to display or link to non-quantitative metadata? (including captions, labels, etc.)
10. **Display Modes** | What display modes might be used in experiencing your display?



Now, visit the [10QViz conversation!](#) There's so much more to talk about.



Arzu Çöltekin
10QViz co-founder
(with Alyssa Goodman)

Curious about the **origins** of 10QViz? Try the [About](#) page.

Want to learn **how best to use** and **participate** in 10QViz? Try the [How to](#) page.

Want to read about the **scholarship** behind 10QViz.org's questions? Try [Coltekin & Goodman 2018](#).



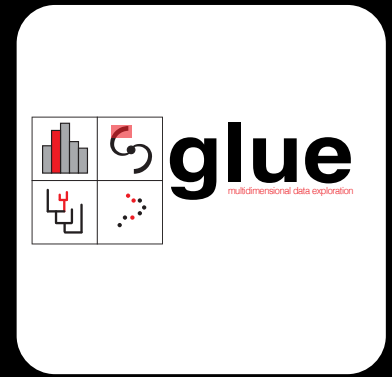
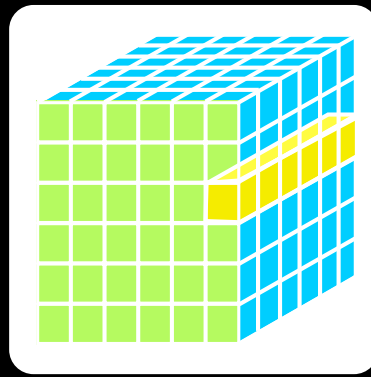
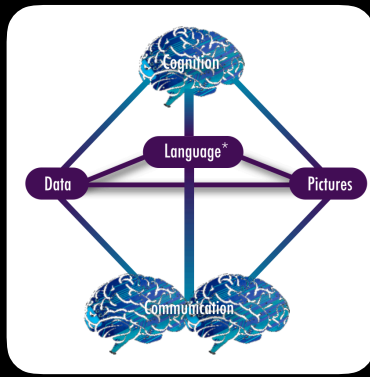
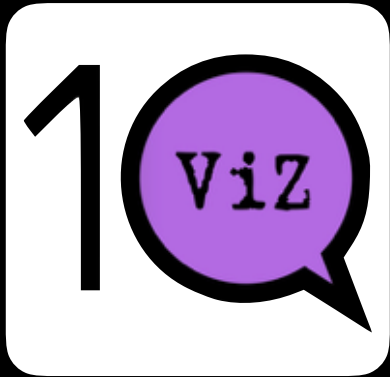
(VISUALIZATION IN >>20 MIN)

The 10 Questions

1. **Who** | Who is your audience? How expert will they be about the subject and/or display conventions?
 2. **Explore-Explain** | Is your goal to explore, document, or explain your data or ideas, or a combination of these?
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-

10QVIZ.ORG

VISUALIZATION IN



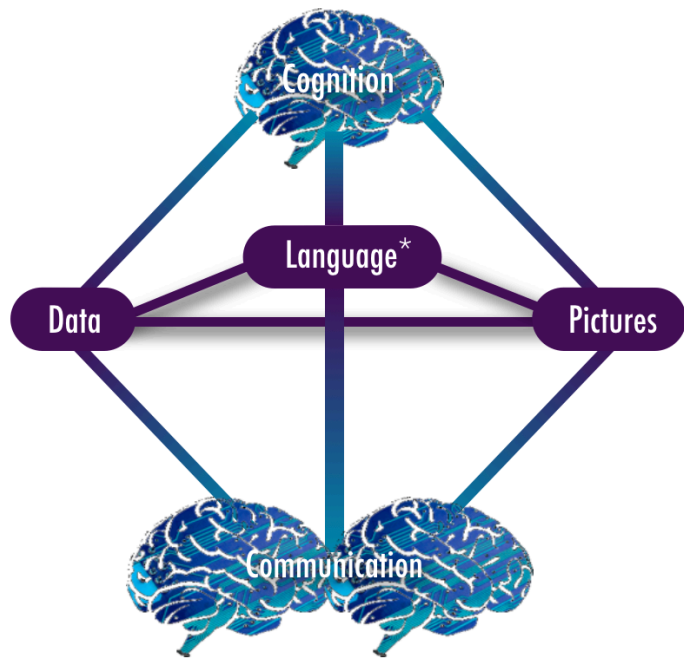
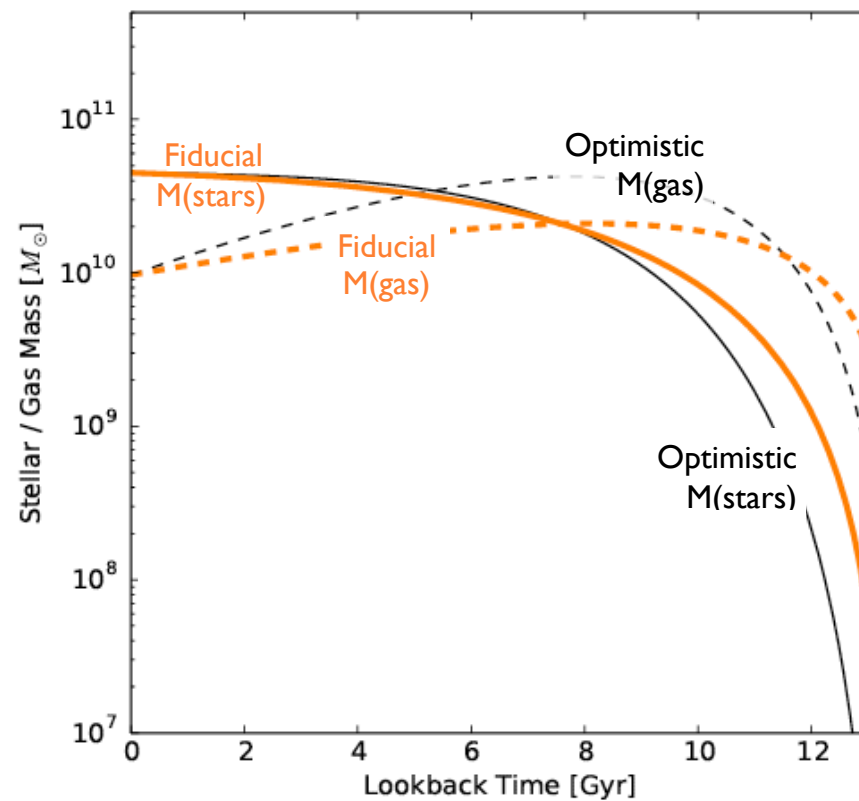
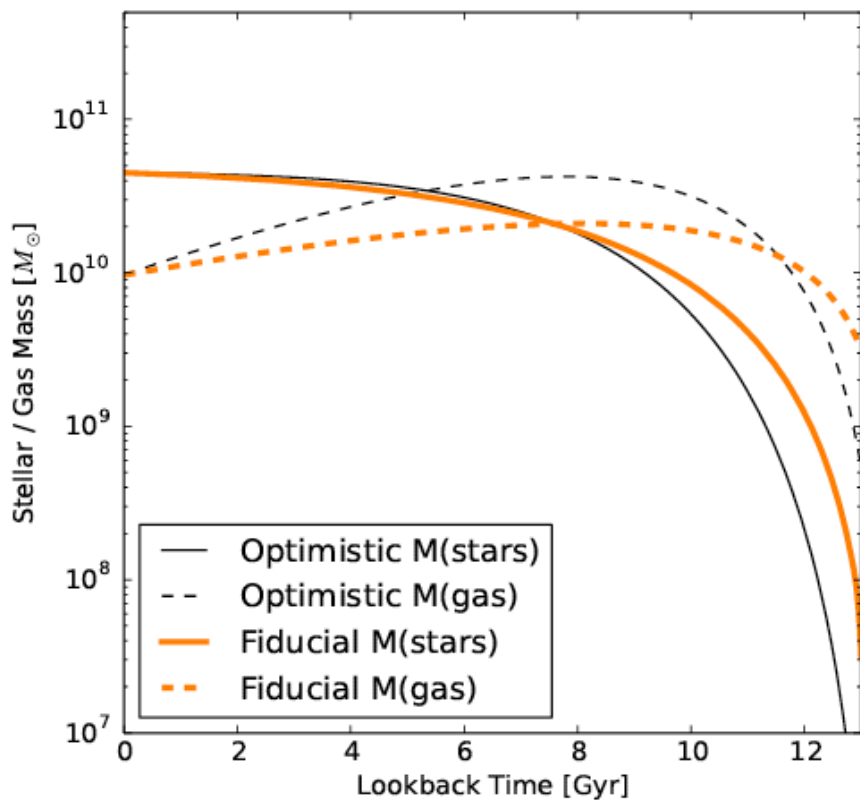
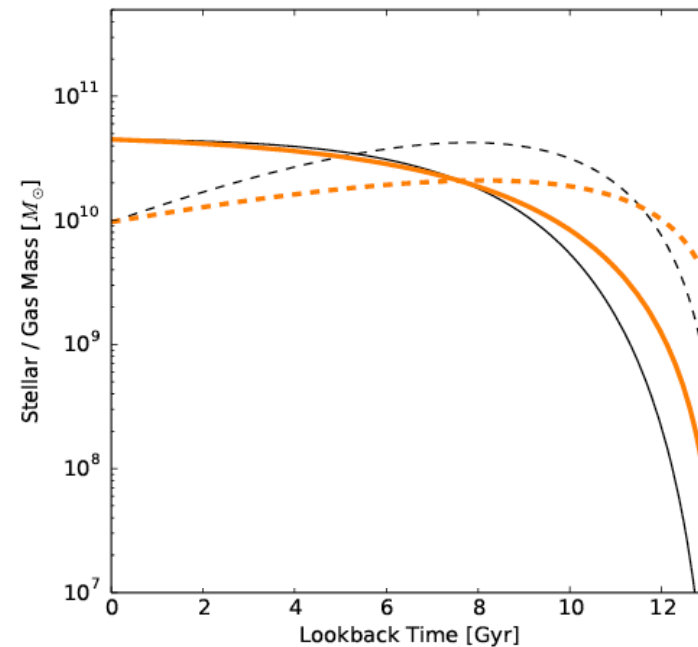
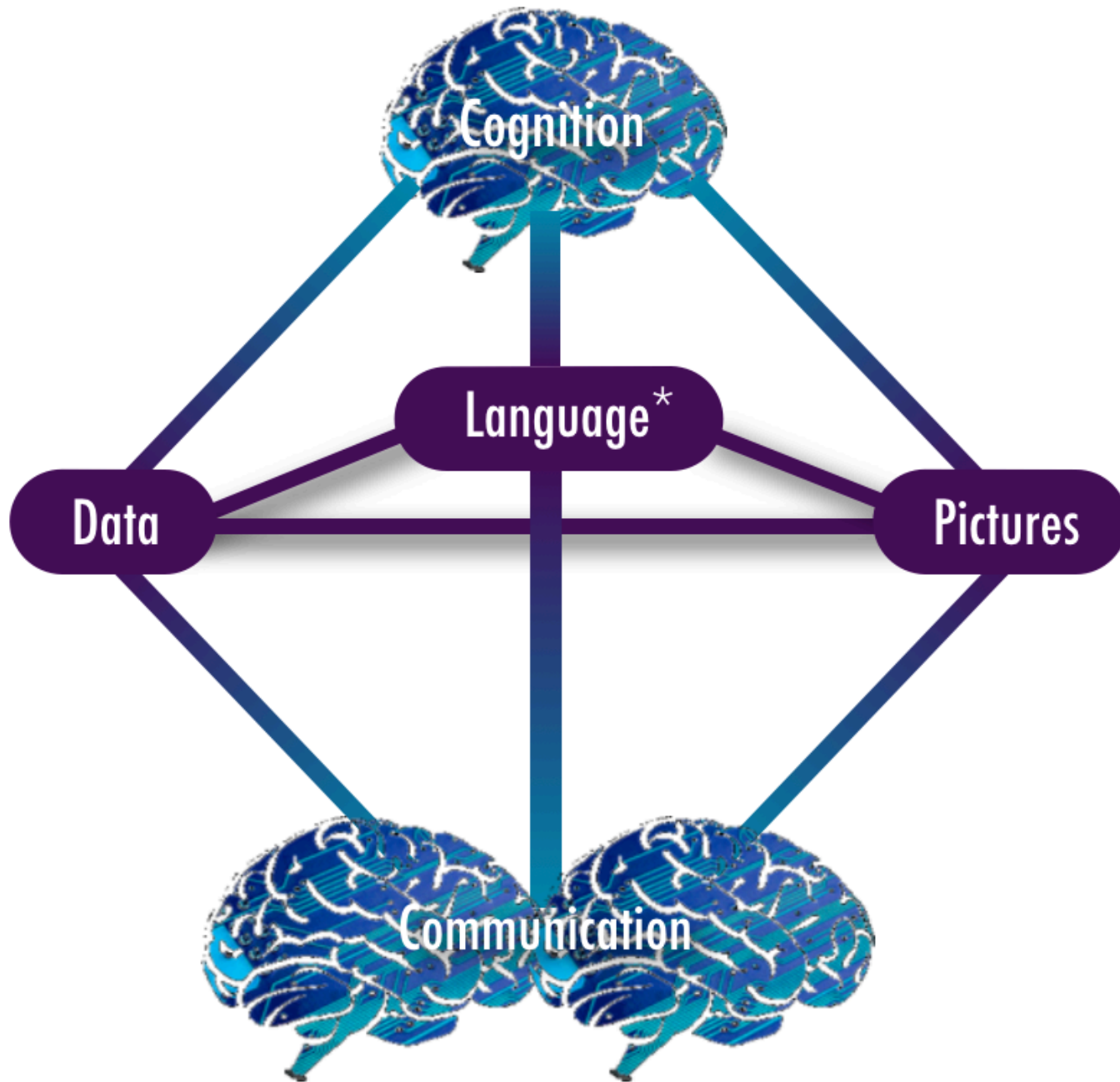


Figure Caption: The solid/solid black line shows the optimistic case for $M(\text{stars})/M(\text{gas})$. The orange lines show the same quantities, for the fiducial case.





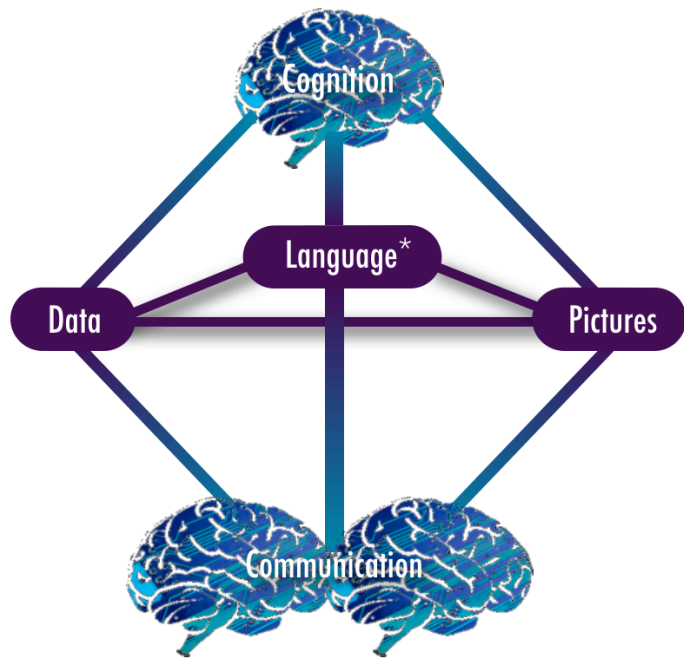
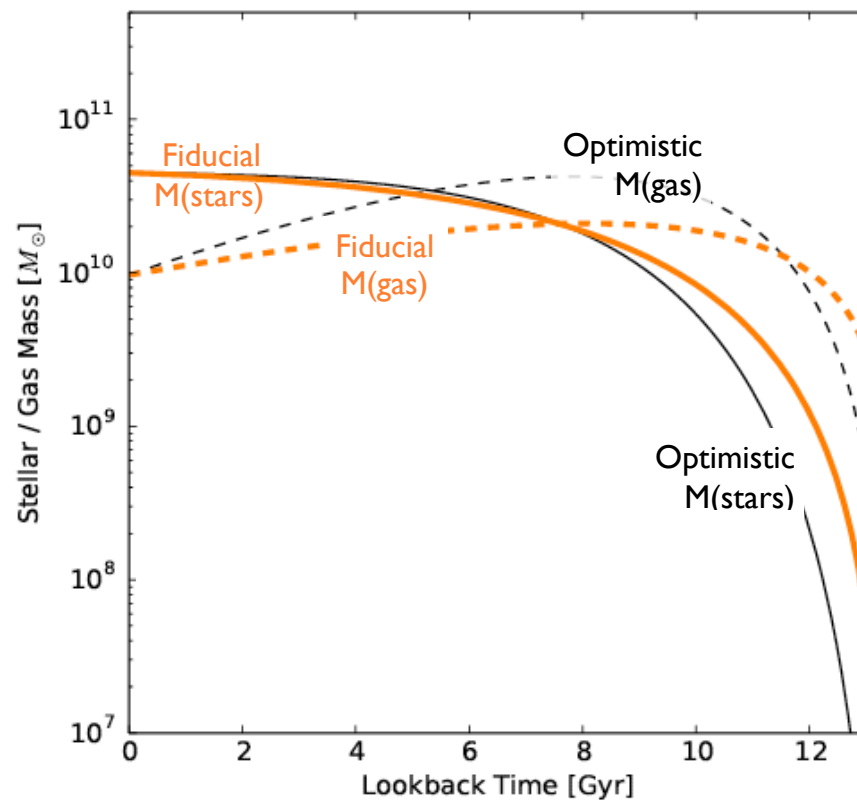
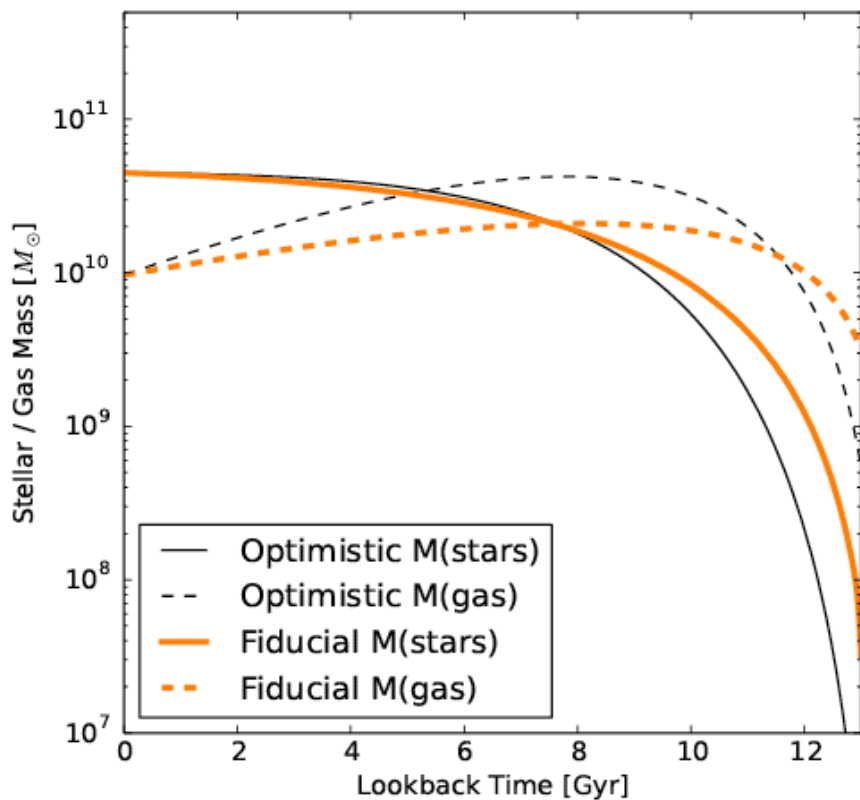
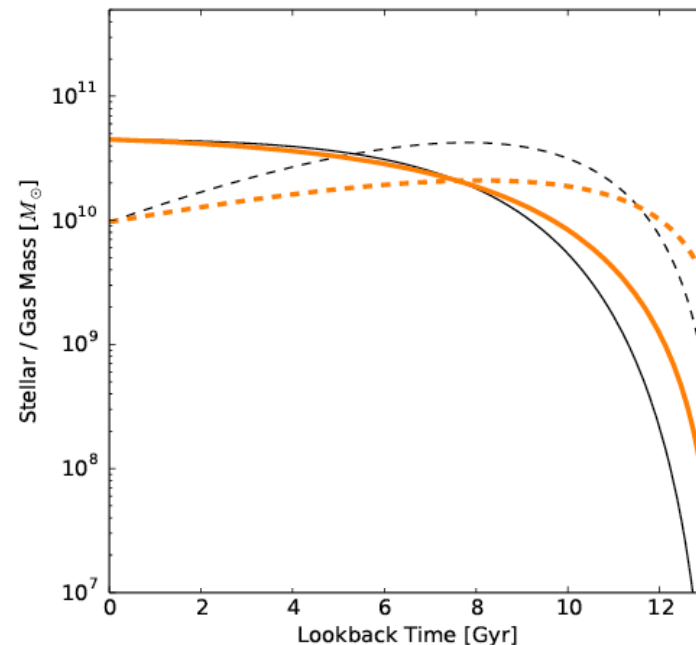
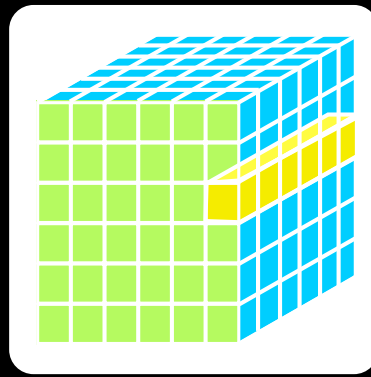
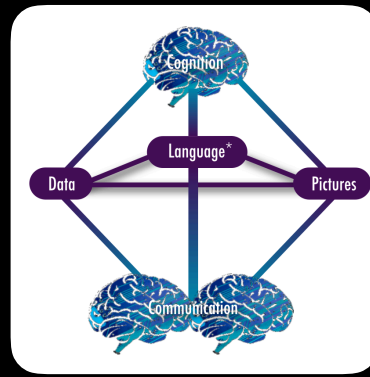
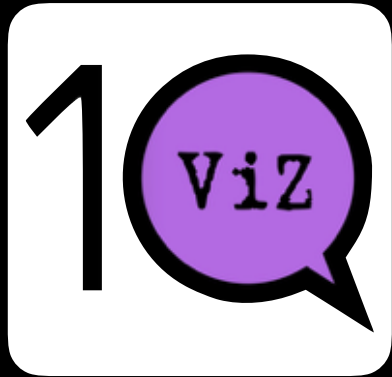


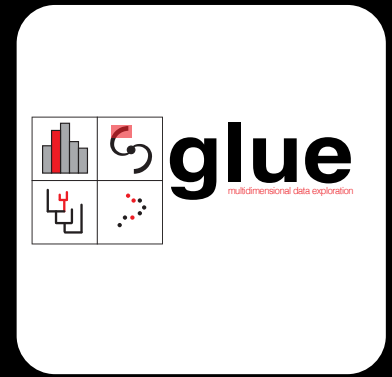
Figure Caption: The solid/solid black line shows the optimistic case for $M(\text{stars})/M(\text{gas})$. The orange lines show the same quantities, for the fiducial case.



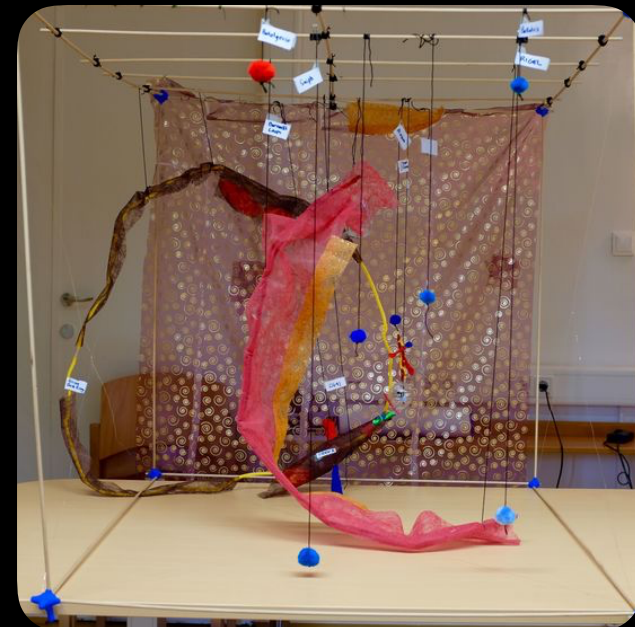
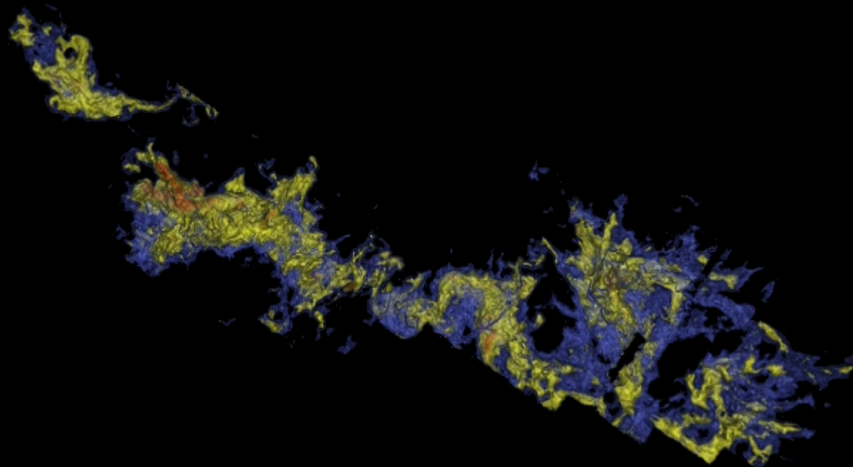
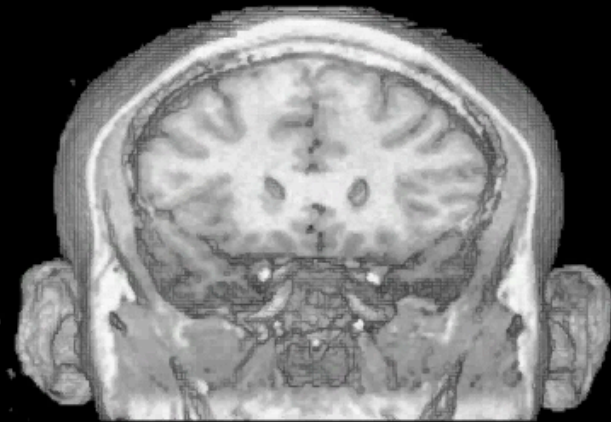
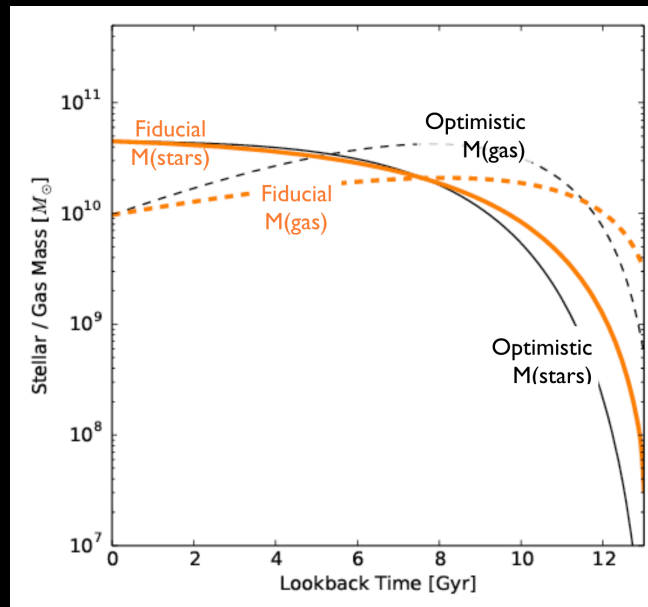
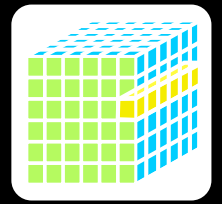
VISUALIZATION IN



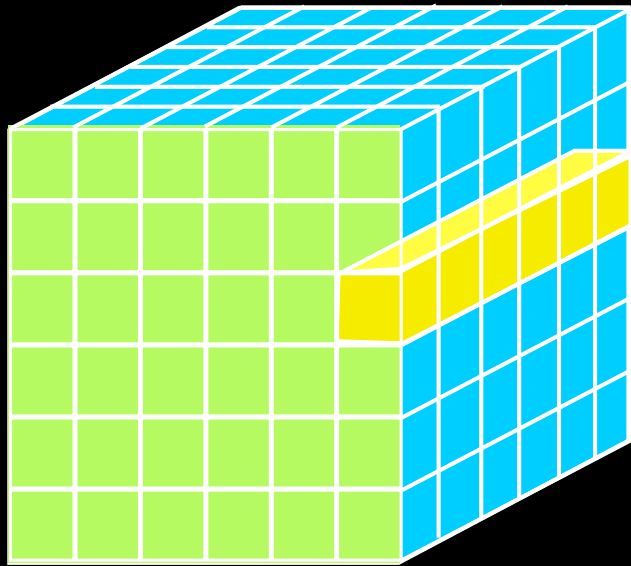
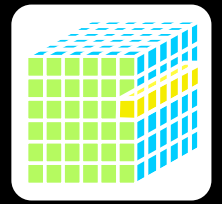
Big DATA
versus
Wide DATA



"DATA, DIMENSIONS, DISPLAY"



"DATA, DIMENSIONS, DISPLAY"



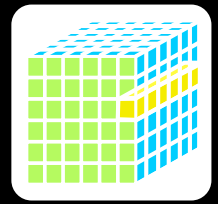
1D: Columns = "Graphs"

2D: Faces or Slices = "Images"

3D: Volumes = "3D Renderings", "2D Movies"

4D: Time Series of Volumes = "3D Movies"

"DATA, DIMENSIONS, DISPLAY"



Home Explore Guided Tours Search Communities View Settings Install Windows Client Sign Out

Collections > Open Collections > Bar-pt1-pl003_sm > f1 WorldWide Telescope

Layers

- Sky
 - Overlays
 - Constellations
 - Constellation Pictures
 - Constellation Figures
 - Constellation Boundaries
 - Constellation Names
 - Grids
 - Equatorial Grid
 - Galactic Grid
 - AltAz Grid
 - Ecliptic Grid
 - Ecliptic Overview
 - Precession Chart
 - 2d Sky
 - Show Solar System
 - 3d Solar System
 - Milky Way (Dr. R. Hurt)
 - Stars (Hipparcos, ESA)
 - Planets (NASA, ETAL)
 - Planetary Orbits
 - Moon & Satellite Orbits
 - Asteroids (IAU MPC)

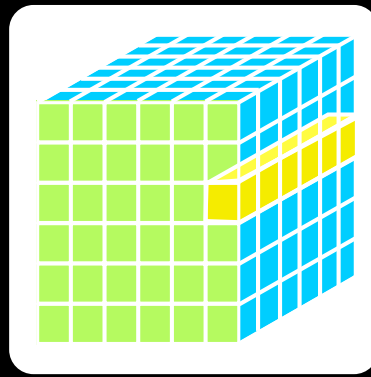
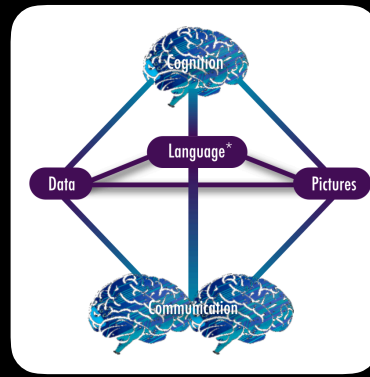
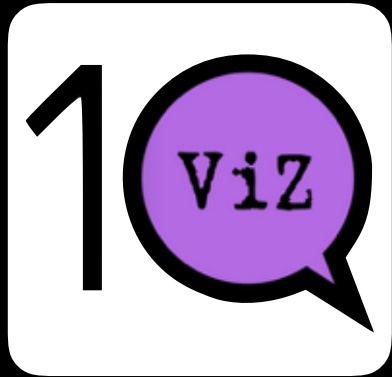
Look At: Sky Imagery: Digitized Sky Survey (Color) Image Crossfade:

Tracking: Bar-pt1-pl003_sm 1 of 28

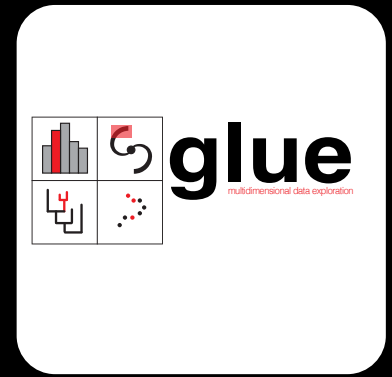
Perseus 19:26:35
RA: 03h37m14s
Dec: +31:25:52

NGC 1333 IC348 Perseus A: A NGC 1275 Freewheeling California Nebula Barnard 3 Barnard 3 California Nebula Image File

VISUALIZATION IN



Big DATA
versus
Wide DATA



"DATA, DIMENSIONS, DISPLAY"


The screenshot displays a web-based astronomical software interface. At the top, a navigation bar includes 'Home', 'Explore', 'Guided Tours', 'Search', 'Communities', 'View', and 'Settings'. On the right, there are buttons for 'Install Windows Client' and 'Sign Out'. Below the navigation bar, the breadcrumb path reads 'Collections > Open Collections > Bar-pt1-pl003_sm'. A 'WorldWide Telescope' logo is visible in the top right corner. The main display area shows a 3D grid overlay on a star field, with a central rectangular window highlighting a specific region. On the left, a 'Layers' panel lists various options: Sky, Overlays (Constellations, Grids, 2d Sky, 3d Solar System), and other celestial features. At the bottom, a 'Look At' section shows a 3D grid icon and a 'Big DATA versus Wide DATA' graphic. The 'Image Crossfade' section displays a sequence of images including NGC 1333, California Nebula, and Barnard 3. On the right, a 'Tracking' section shows the current object 'Bar-pt1-pl003_sm' and a 'Perseus' constellation map with coordinates RA: 03h37m14s and Dec: +31.25.52.


"DATA, DIMENSIONS, DISPLAY"


Image size: 520 x 274


View size: 1305 x 733

VL: 63 WW: 127

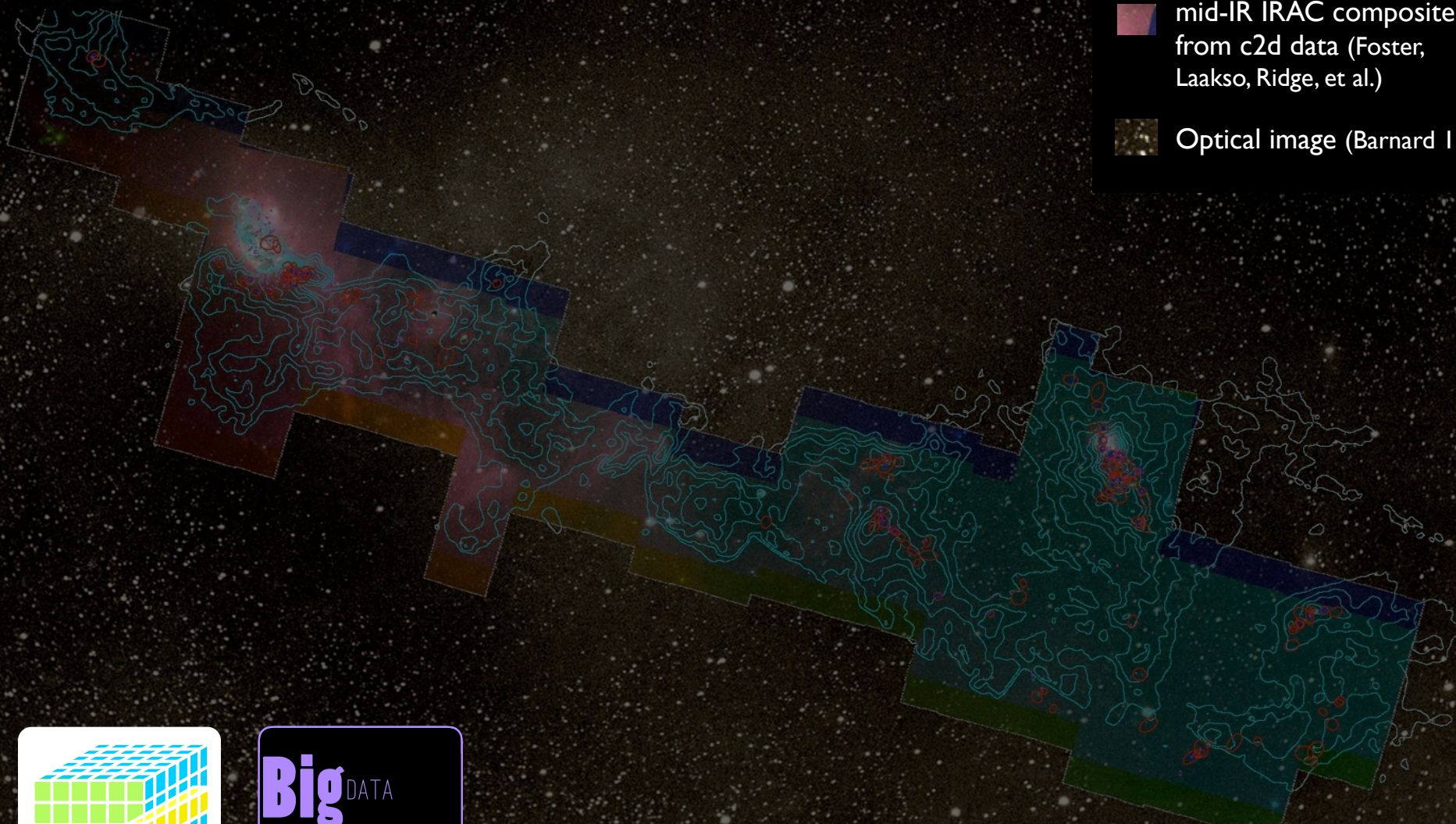
 mm peak (Enoch et al. 2006)

 sub-mm peak (Hatchell et al. 2005, Kirk et al. 2006)

 ^{13}CO (Ridge et al. 2006)

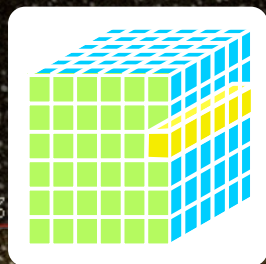
 mid-IR IRAC composite from c2d data (Foster, Laakso, Ridge, et al.)

 Optical image (Barnard 1927)

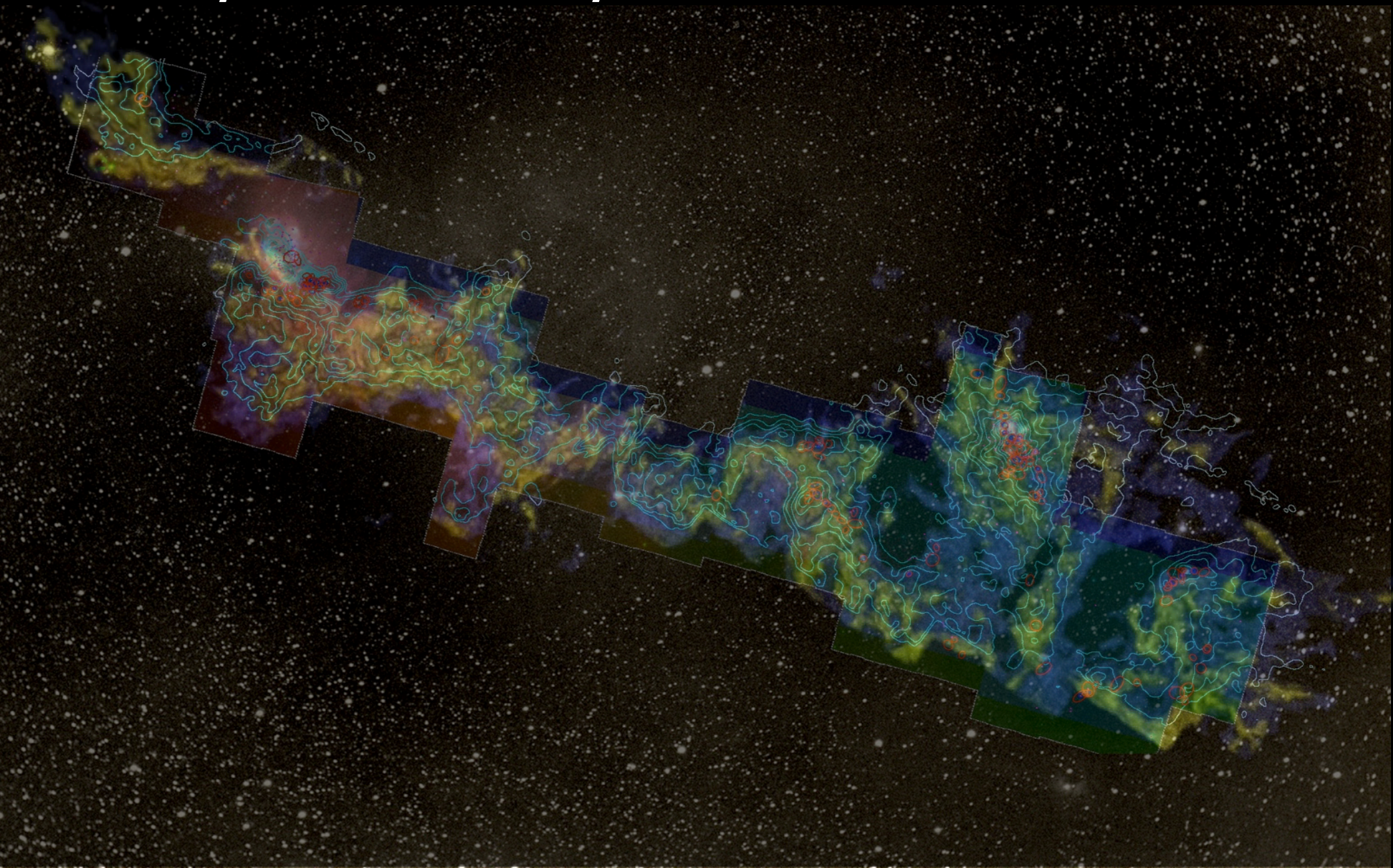


m: 1/249

oom: 227%



"DATA, DIMENSIONS, DISPLAY"



3D Viz made with VolView

CLOSER TO HOME (GLUE & MY FBI FILE)



Glue interface header showing menu items: Data Manager, Plugins, Help. System status: 60% battery, Sun Mar 11 6:42 PM, Alyssa Goodman. A search bar is visible on the right.

Data Component list:

- Subs...
- A Day in the Life of Logan
- Descending
- Climbing
- Landing

Plot Layers - 2D Scatter

- A Day in the Life of Logan (airplane_positions)
- Landing (airplane_positions)
- Climbing (airplane_positions)
- Descending (airplane_positions)
- nearground (airplane_positions)

Color, Points, Line, Errors, Vectors

color: Fixed (Yellow)

opacity: [Slider]

Plot Options - 2D Scatter

General Limits Axes

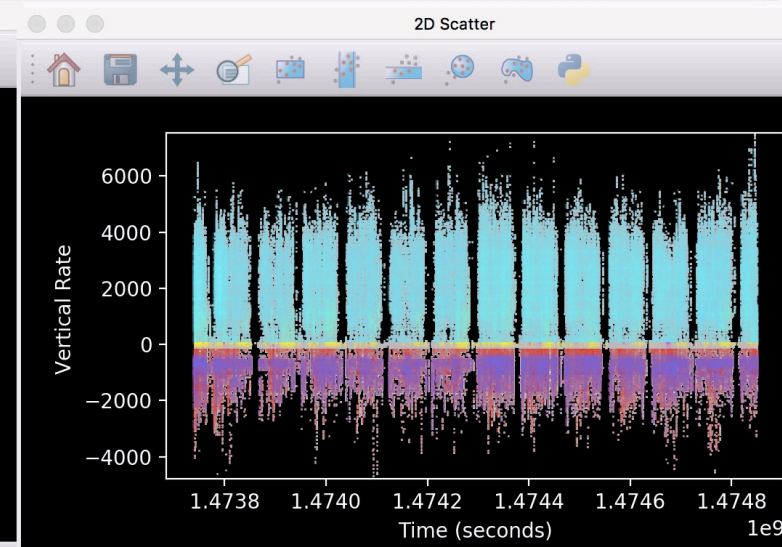
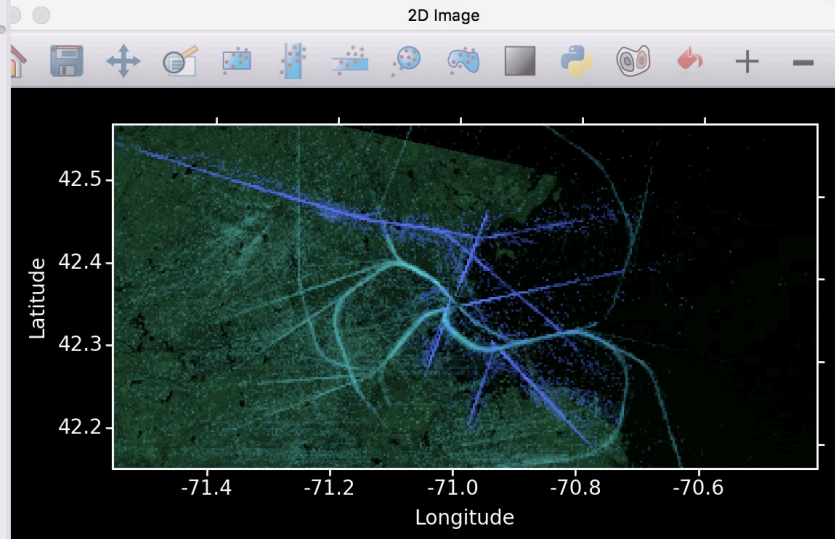
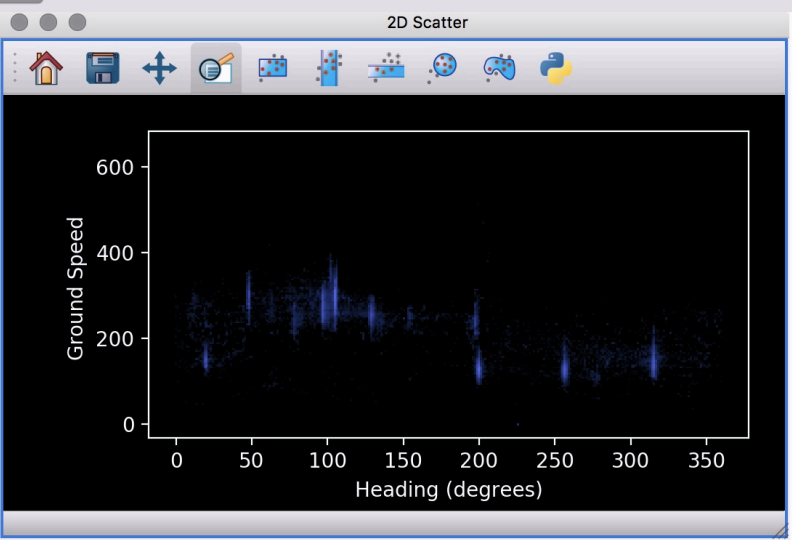
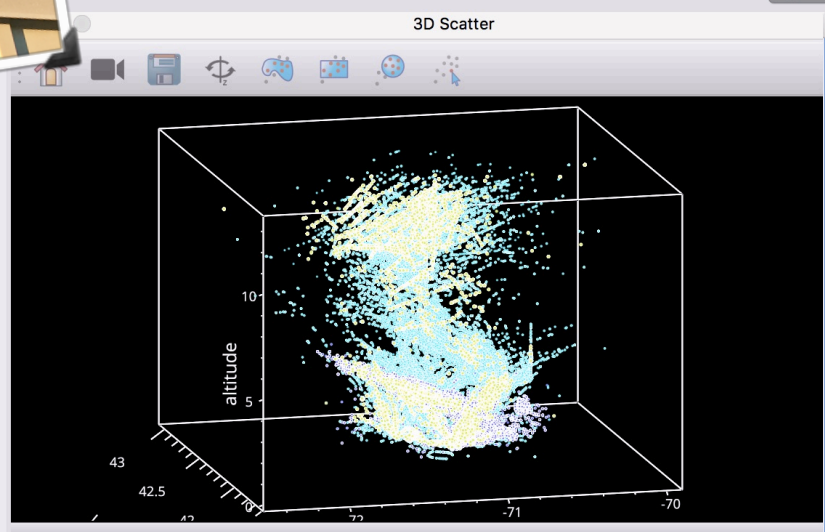
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y label: Ground Speed

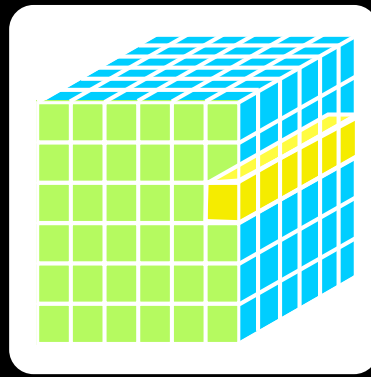
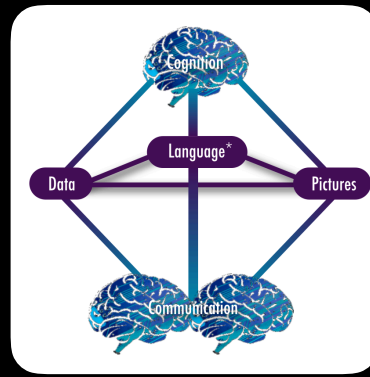
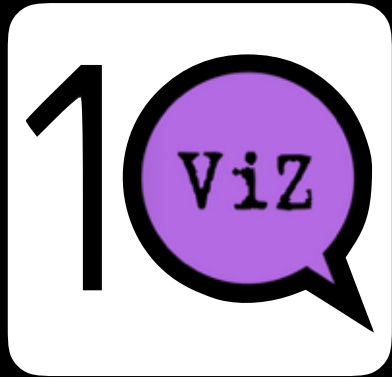
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axis label weight: medium

tick label size: 10



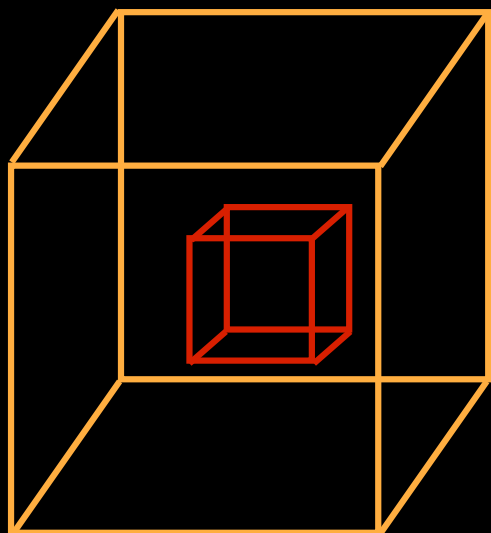
VISUALIZATION IN



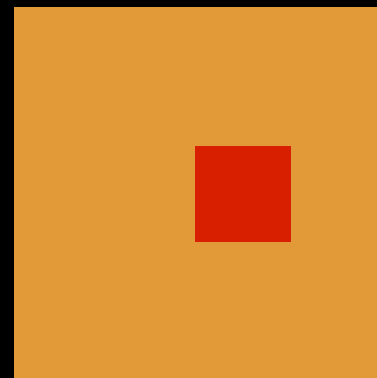
Big DATA
versus
Wide DATA



LINKED VIEWS OF HIGH-DIMENSIONAL DATA

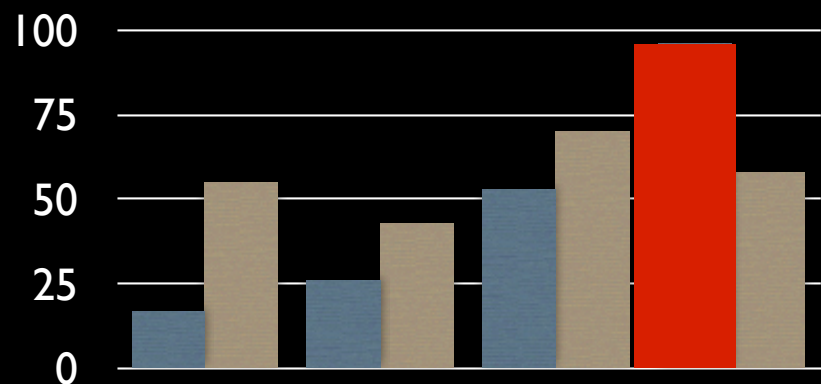


3D

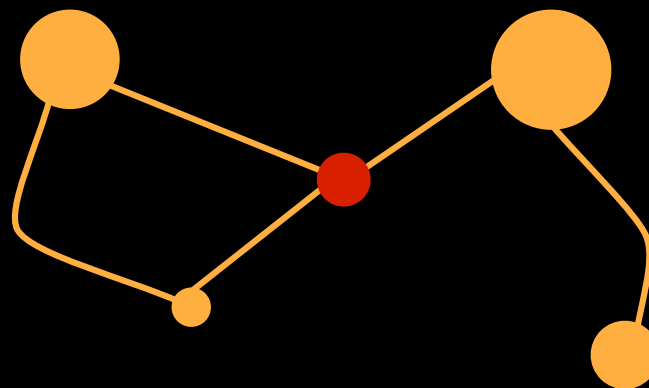


2D

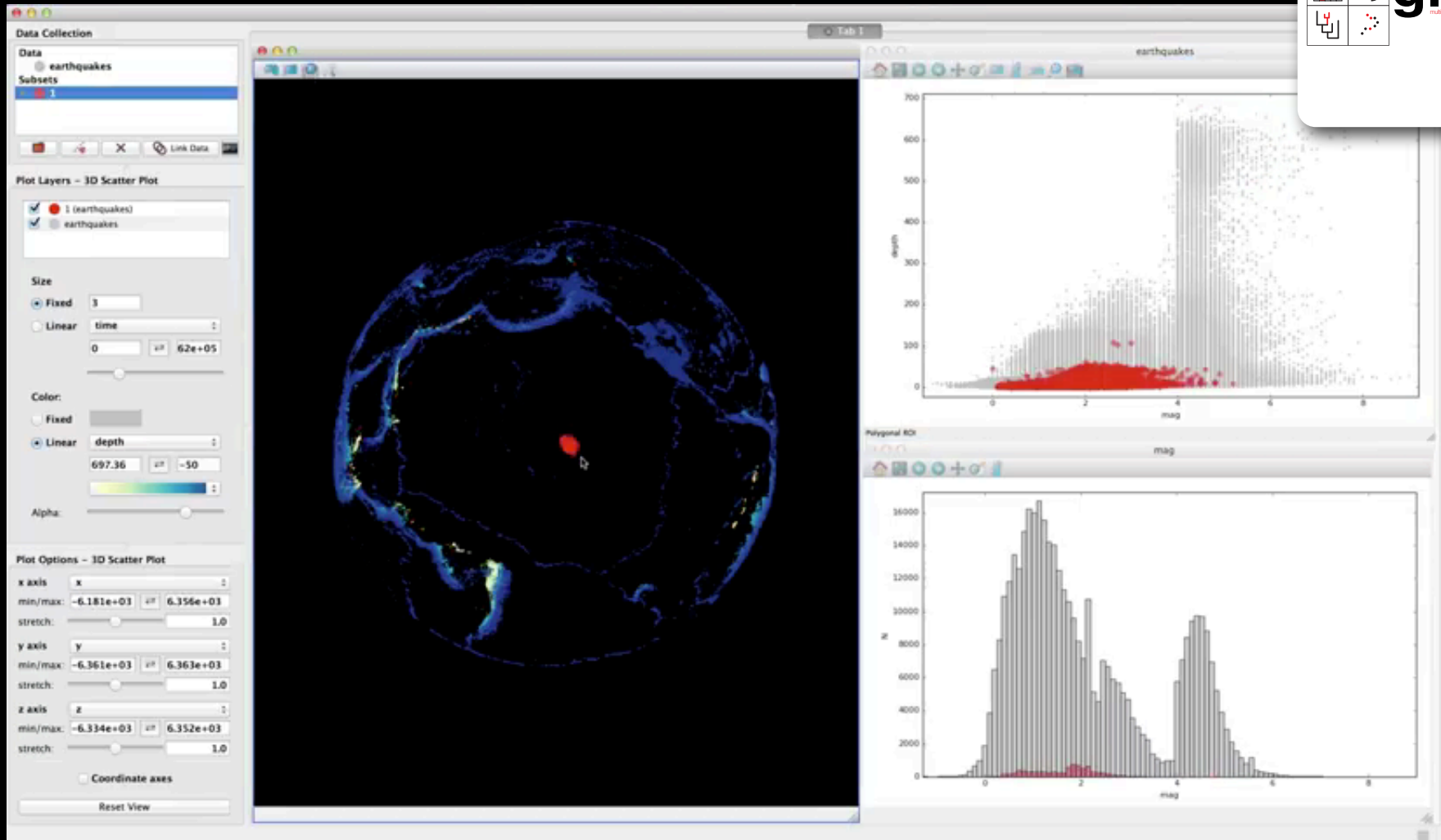
Statistics



Data Abstraction

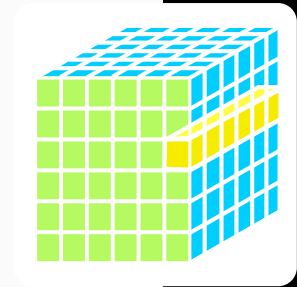
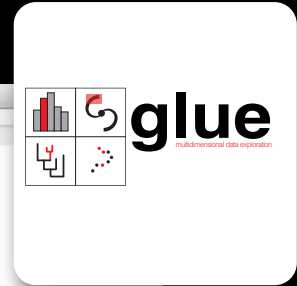
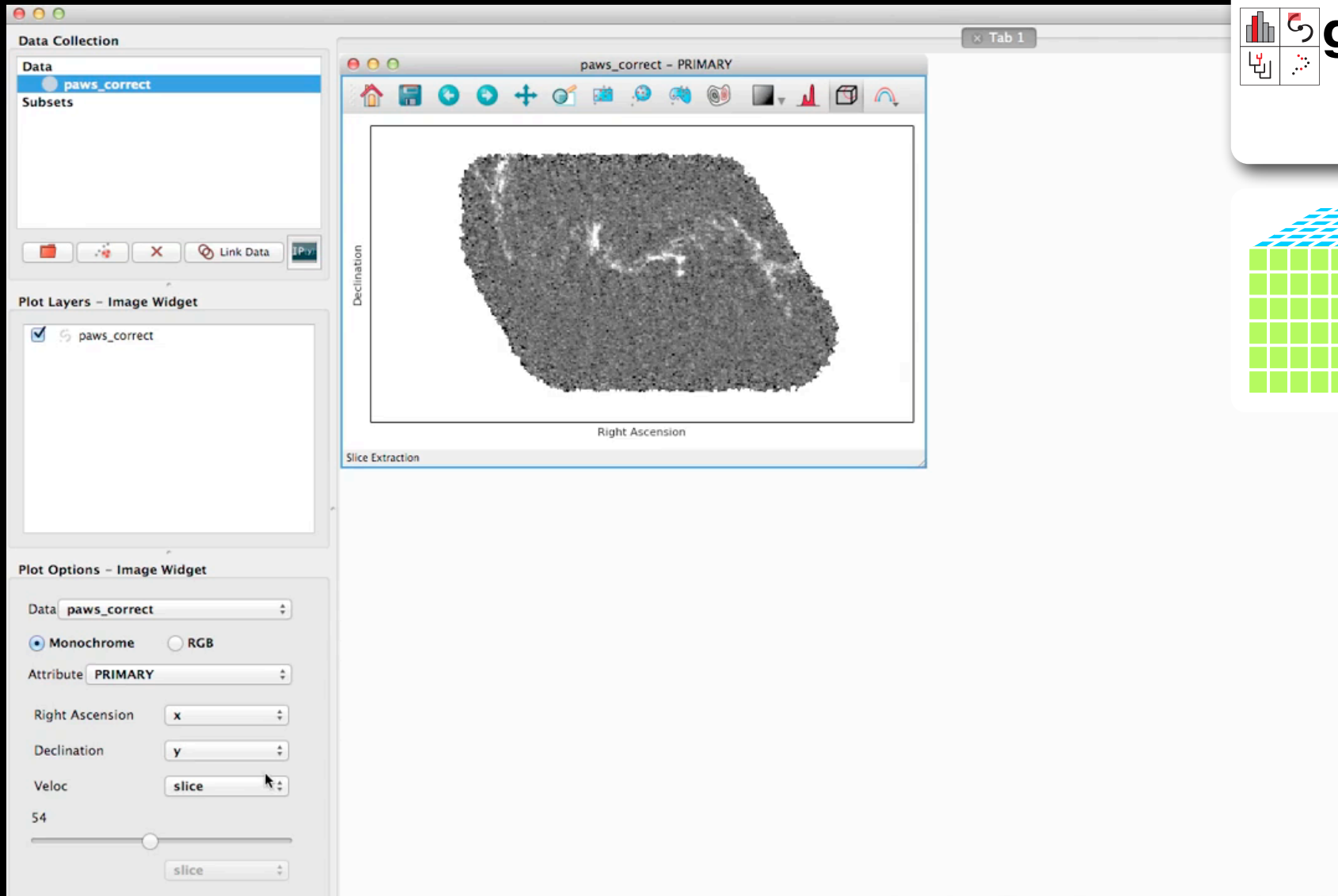


LINKED VIEWS OF HIGH-DIMENSIONAL DATA, IN PYTHON



*video by Tom Robitaille, lead glue developer
glue created by: C. Beaumont, M. Borkin, P. Qian, T. Robitaille, and A. Goodman, PI*

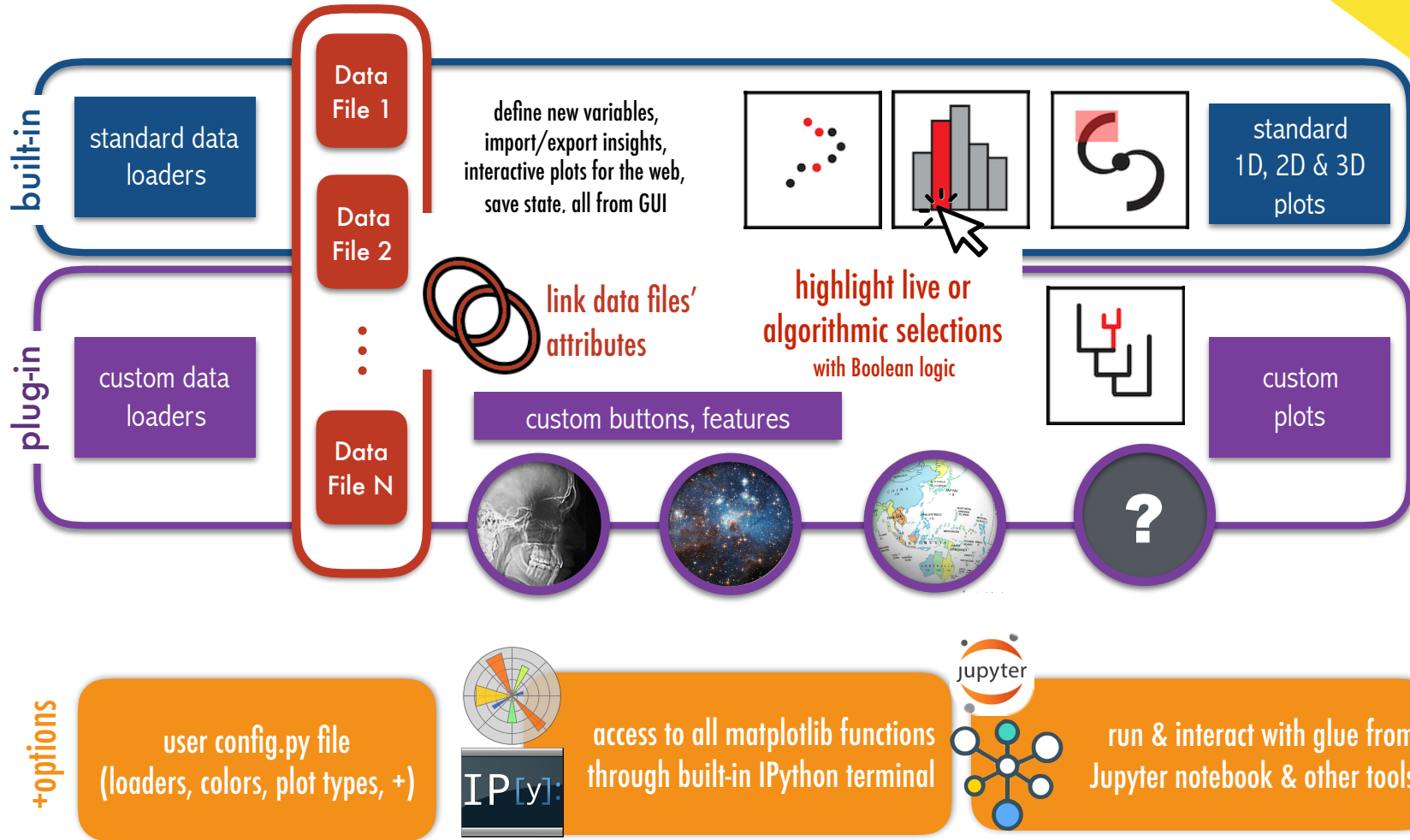
LINKED VIEWS OF HIGH-DIMENSIONAL DATA, IN PYTHON



*video by Chris Beaumont, glue developer
glue created by: C. Beaumont, M. Borkin, P. Qian, T. Robitaille, and A. Goodman, PI*

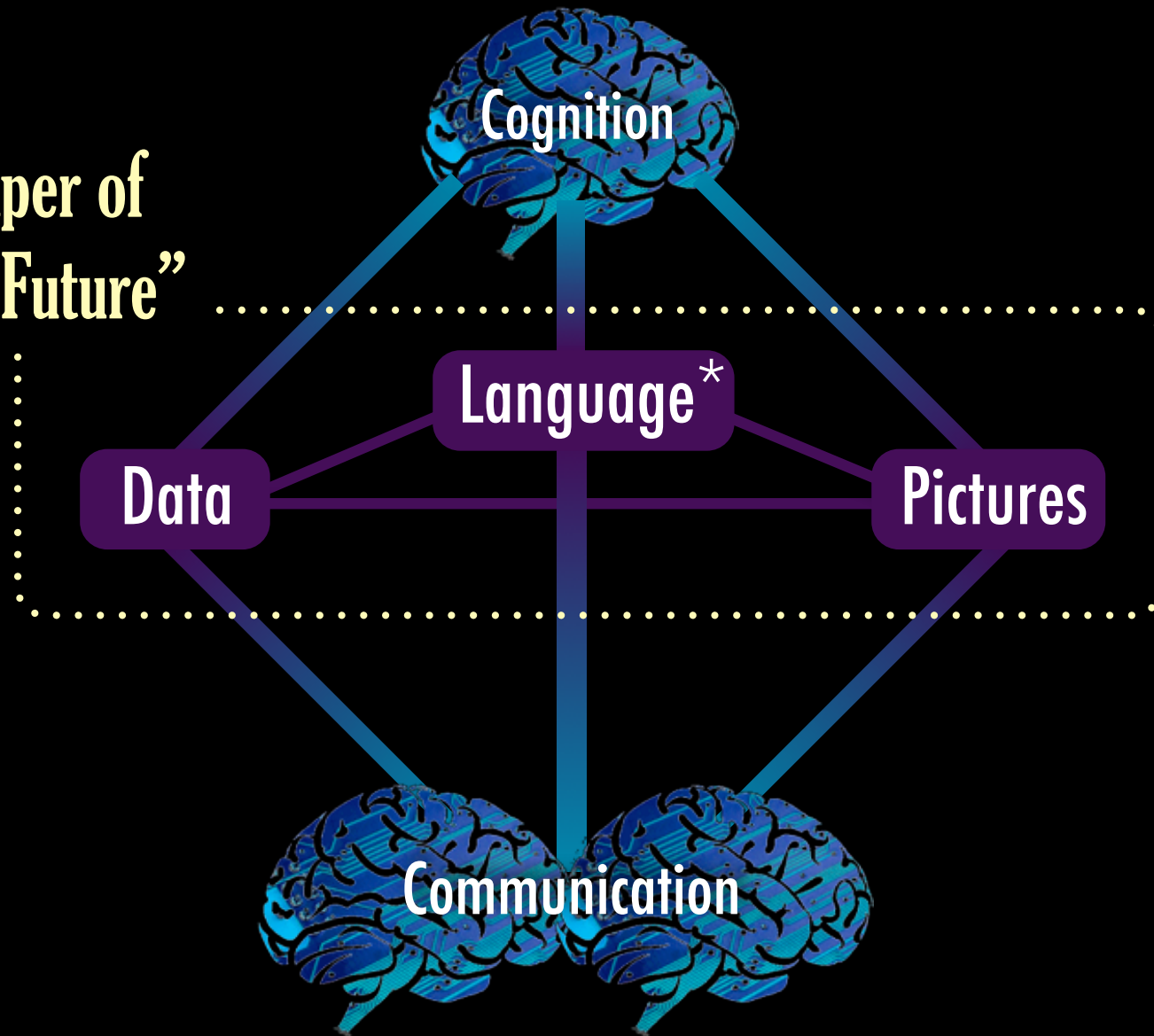


your handout

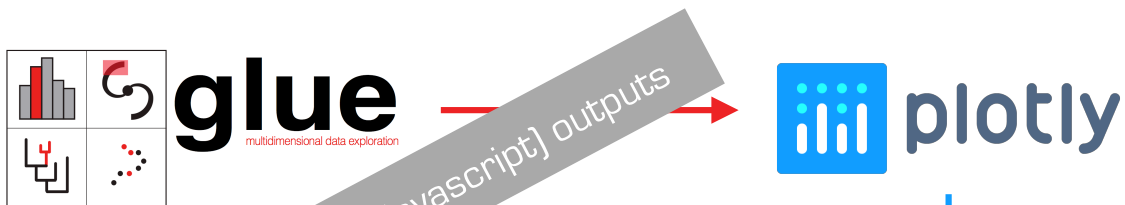


glueviz.org

“Paper of
the Future”



*"Language" includes words & math



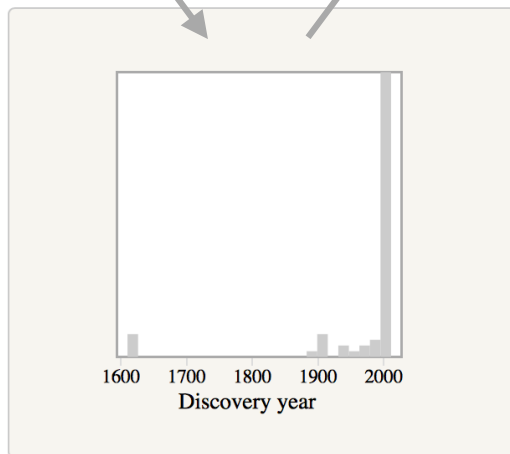
d3po

d3po is a project designed to allow an astronomer (or anyone), with no special data visualization skills, to make an interactive, publication-quality figure that has staged builds and linked brushing through scatter plots. Our current version can be previewed at d3po.org, and represents a figure from upcoming work by graduate student Elisabeth Newton. The figure describes how metallicity affects color in cool stars, and represents a nice use case for d3po. Try clicking and dragging in the scatter plots to understand the power of linked brushing in published figures.

Right now we are in search of alpha testers, who have figures that could be made interactive and who are willing to get their hands a little dirty (No javascript skills needed). In future versions, we plan to link to glue to allow the creation of d3po figures interactively. We are also exploring [implementation](#) of d3po within presentations and within [authorea](#). Full 1.0 version expected in January 2014.

Installing your own d3po server

```
git clone git@github.com:adm/d3po.git
cd d3po
virtualenv --no-site-packages venv
source venv/bin/activate
pip install -r pip-requirements.txt
python run.py
```



Four Centuries of Discovery | A Chasm in Mass | Little Siblings | Close Cousins | The Strangers

After Galileo discovered the first four moons of Jupiter, it took nearly three hundred years to discover the next one.

Authorea

Authorea Beta

Document Format Insert

markdown **The "Paper" of the Future**

Authorea preprint 02/21/2017 DOI: 10.22541/au.148769949.92783646

Alyssa Goodman (Harvard University)
 Josh Peek (Space Telescope Science Institute)
 Alberto Accomazzi (Harvard-Smithsonian Center for Astrophysics (CFA))
 Chris Beaumont (Harvard-Smithsonian Center for Astrophysics (CFA))
 Christine L. Borgman (UCLA - University of California, Los Angeles)
 Hope How-Huan Chen (Harvard University)
 Merce Crosas (Harvard University)
 Christopher Erdmann (North Carolina State University)

And 3 more...

Add Collaborator Manage

markdown A 5-minute video demonstration of this paper is available at [this YouTube link](#).

1 Preamble

A variety of research on human cognition demonstrates that humans learn and communicate best when more than one processing system (e.g. visual, auditory, touch) is used. And, related research also shows that, no matter how technical the material, most humans also retain and process information best when they can put a narrative "story" to it. So, when considering the future of scholarly communication, we should be careful not to do blithely away with the linear narrative format that articles and books have followed for centuries; instead, we should enrich it.

Much more than text is used to communicate in Science. Figures, which include images, diagrams, graphs, charts, and more, have enriched scholarly articles since the time of Galileo, and ever-growing volumes of data underpin most scientific papers. When scientists communicate face-to-face, as in talks or small discussions, these figures are often the focus of the conversation. In the best discussions, scientists have the ability to manipulate the figures, and to access underlying data, in real-time, so as to test out various what-if scenarios, and to explain findings more clearly. **This short article explains—and shows with demonstrations—how scholarly "papers" can morph into long-lasting rich records of scientific discourse**, enriched with deep data and code linkages, interactive figures, audio, video, and commenting.

Fig. 1

The Paper of the Future should include seamless linkages amongst data, pictures, and language, where "language" includes both words and math. When an individual attempts to understand each of these kinds of information, different cognitive functions are utilized: communication is inefficient if the channel is restricted primarily to language, without easy interconnection to data and pictures.

[demo]

Many thanks to Alberto Pepe, Josh Peek, Chris Beaumont, Tom Robitaille, Adrian Price-Whelan, Elizabeth Newton, Michelle Borkin & Matteo Cantiello for making this possible.



**Custom Parts
Organizer Box
Included!**

COMING NEXT: GLUE IN THE BROWSER

The screenshot displays a JupyterLab environment with several components:

- Code Editor:** Shows the command `app.scatter3d('x', 'y', 'z');` in a Python 3 kernel.
- Output View:** Displays a 2D histogram of data points with a y-axis labeled "Number" ranging from 0.00 to 70.00 and an x-axis labeled "z" ranging from -3 to 1. The histogram bars are colored in a gradient from orange to black.
- 3D Scatter Plot:** A 3D visualization of the data points, with a central cluster of orange points and a surrounding cloud of grey points. The axes are labeled x, y, and z.
- Modal Window:** A "Start a new activity" dialog box is open, offering three options: "Notebook", "Code Console", and "Text Editor".
- gluepyter Logo:** Located in the bottom left corner, featuring icons for a histogram, a 3D plot, and a code editor, with the text "gluepyter" and "multidimensional data exploration" below it.

Video courtesy of Maarten Breddels, consulting developer



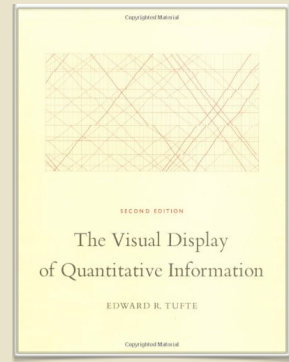
get glue

glueviz.org



HOW Best to Visualize, with examples

READ "The Visual Display of Quantitative Information," Tufte 1983



Graphical Excellence

Graphical Integrity
& "The Lie Factor"

Chartjunk
& Subtraction

Data-ink Ratio

Multi-functioning
graphical elements

Data density

Small multiples

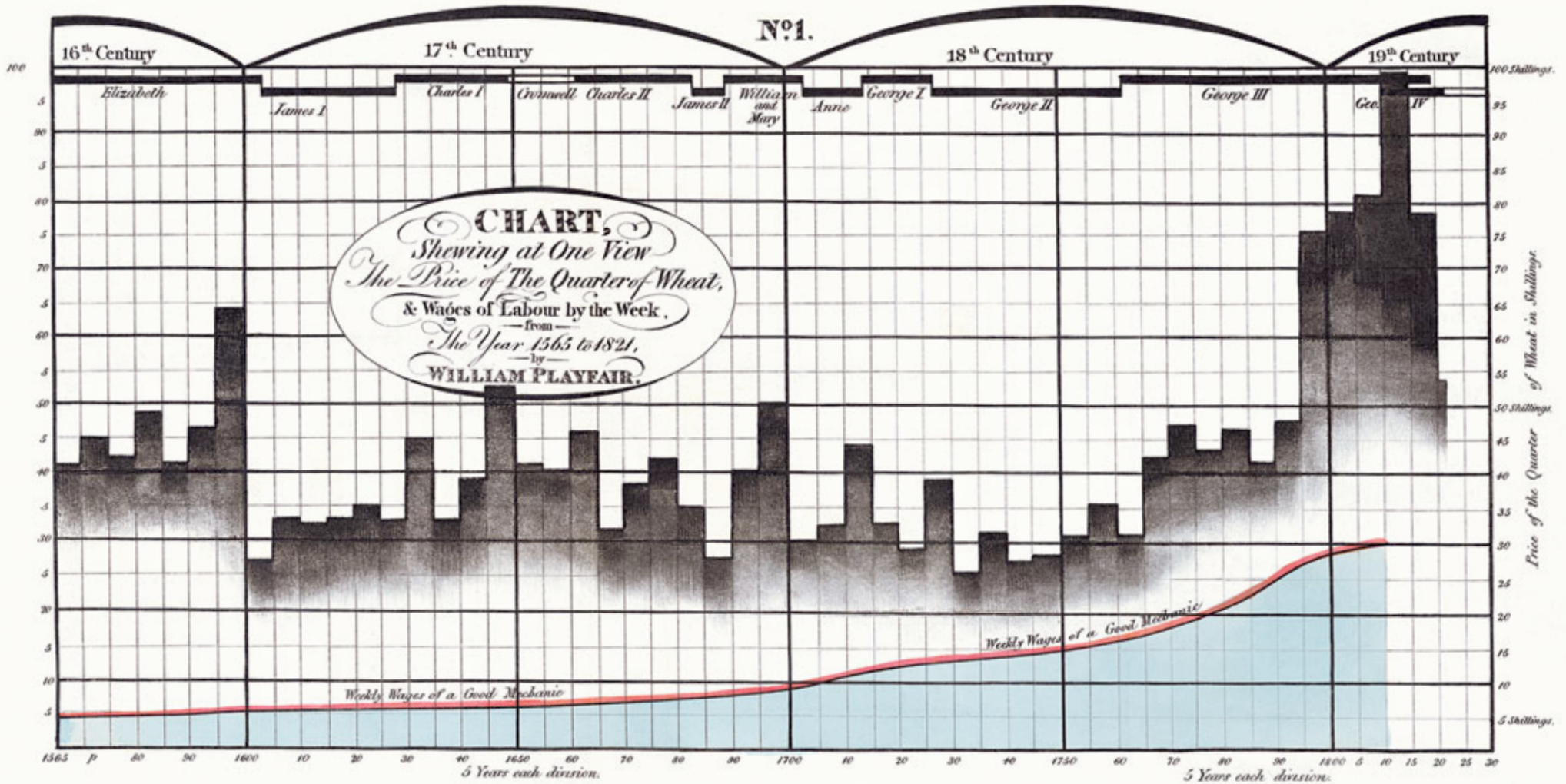
EDWARD TUFTE'S IDEAS

(from "The Visual Display of Quantitative Information," Tufte 1983.)

Graphical Excellence – displays should...

- **show the data**
- induce the viewer to **think** about the **substance** rather than about methodology, graphic design, the technology of graphic production, or something else
- **avoid distorting** what the data have to say
- present **many numbers** in a small space
- make large data sets **coherent**
- encourage the eye to **compare** different pieces of data
- reveal the data at **several levels of detail**, from a broad overview to the fine structure
- serve a reasonably clear **purpose**: description, exploration, tabulation, or decoration
- be closely **integrated** with the statistical and **verbal descriptions** of a data set

Graphical Excellence



William Playfair (1759-1823)

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Graphical Excellence

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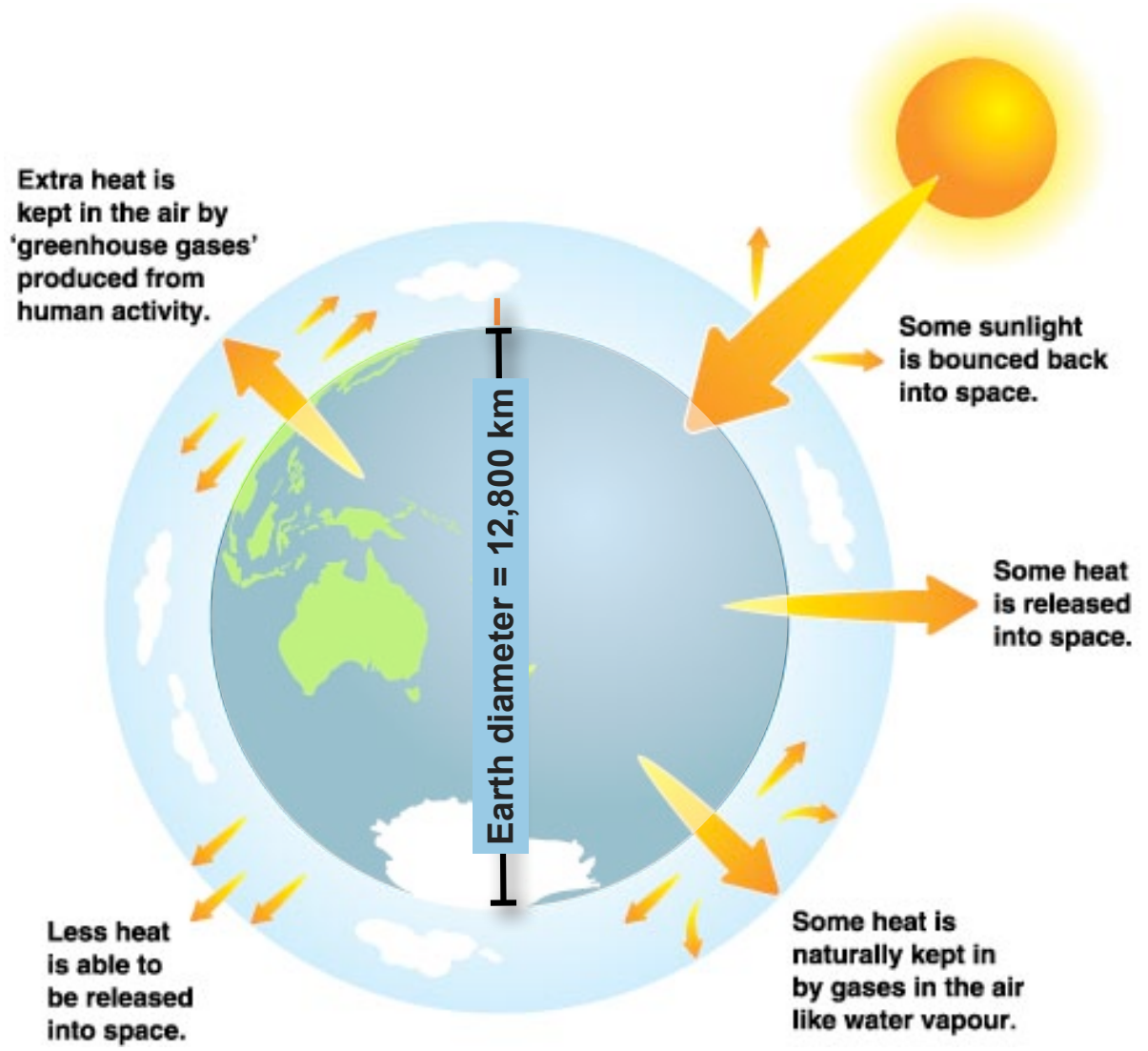
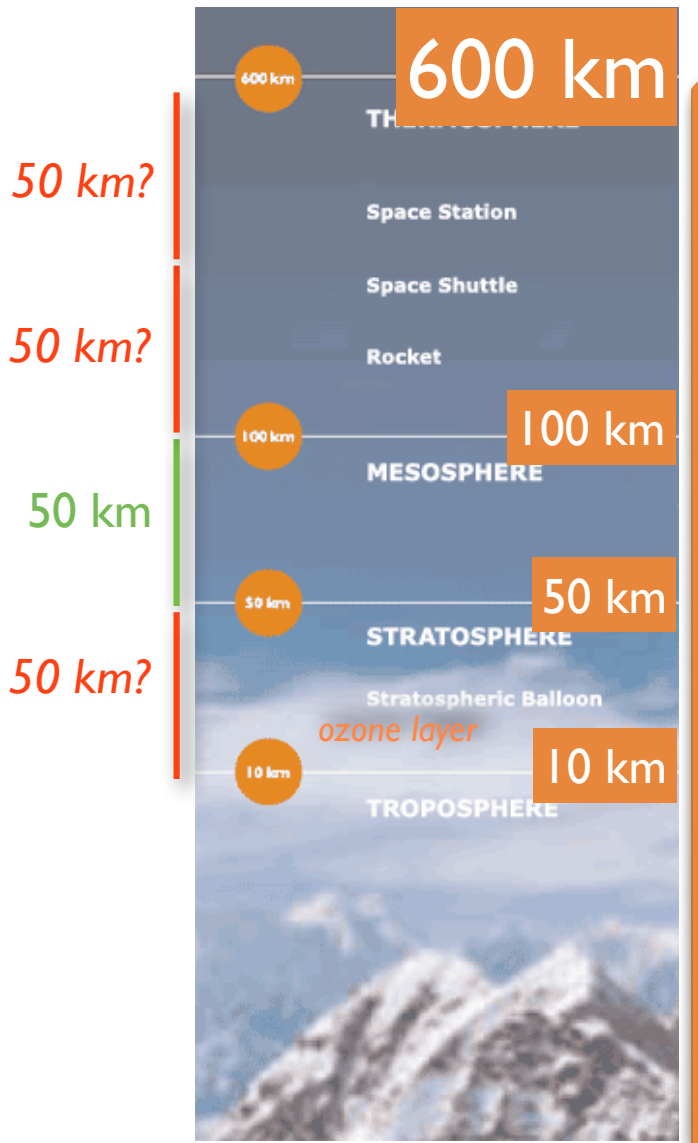
Data-ink Ratio

Multi-functioning
graphical elements

Data density

Small multiples

Graphical Integrity & "The Lie Factor"



EDWARD TUFTE'S IDEAS

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Graphical Excellence

Graphical Integrity
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& Subtraction

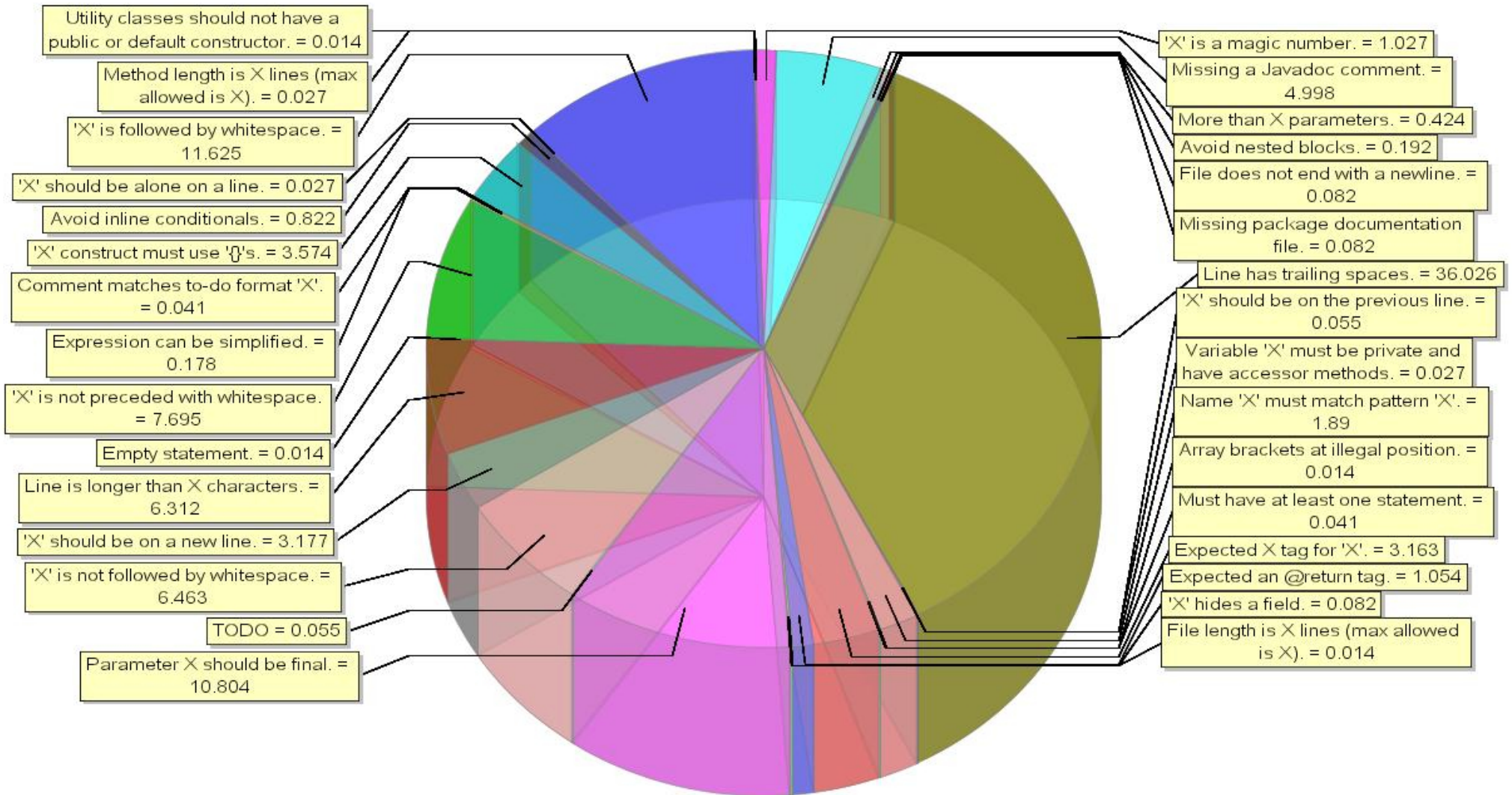
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Chartjunk & Subtraction



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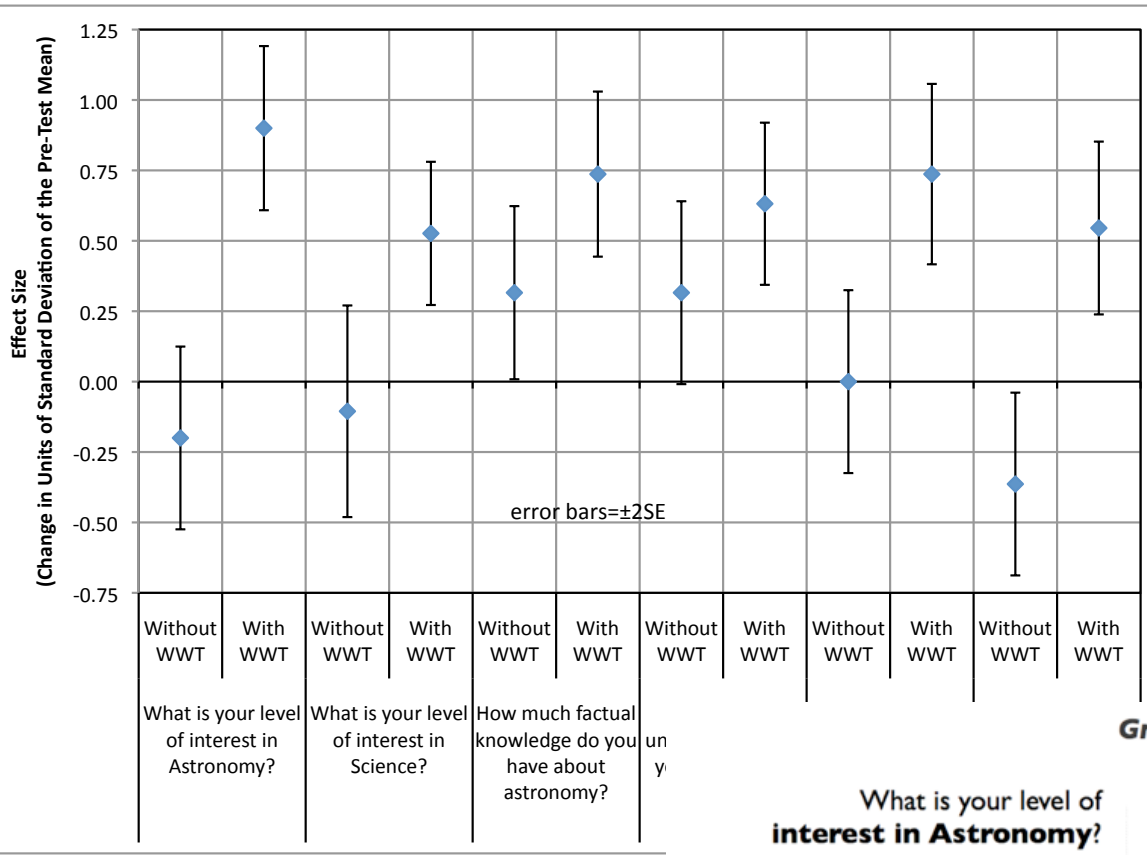
Data-ink Ratio

Multi-functioning
graphical elements

Data density

Small multiples

Data-ink Ratio



Group B (Traditional) $N_{before}=77; N_{after}=75$
Group A (With WWT) $N_{before}=75; N_{after}=81$

What is your level of **interest in Astronomy?**

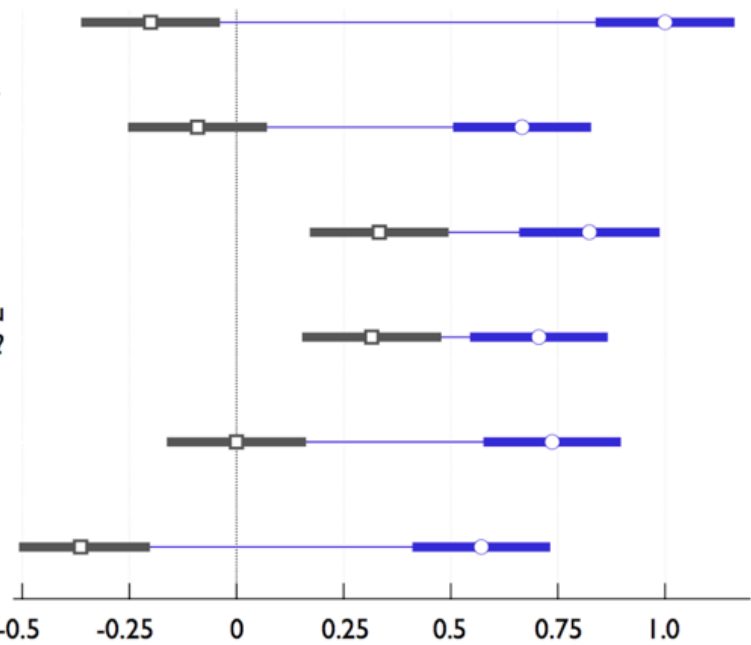
What is your level of **interest in Science?**

How much **factual knowledge** do you have about astronomy?

How much **understanding** do you have about topics in astronomy?

How well can you **visualize** Sun-Earth-Moon relationships?

How interested are you in using a real **telescope?**



Effect Size: Gain (or Loss) in Units of Pre-Test Standard Deviation
 (Error bars show ± 1 Standard Error of the Mean)



from AG example used in

EDWARD TUFTE'S IDEAS

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Multi-functioning graphical elements

Live Scoreboard | Celtics.com

SCOREBOARD

DEN 116	WAS 72	POR 97	PHI 46	MIL 34	DAL 26-11	LAL 25-11
CHA 119	BOS 79	NJN 70	SAS 52	UTA 34	SAC 14-21	SEA 9-27
FINAL	2:34	4th 0:50	4th	Halftime 5:36	2nd 10:00	10:00

COURTSIDE LIVE

72 **02:46** **79**

1	2	3	4	OT	T
18	17	24	13		72
18	18	26	16		79

Fouls: 1 4 0 Fouls: 1 3 1

19-16 30-5

STANDINGS

COURTSIDE LIVE **BOX SCORE** **PLAY-BY-PLAY** Highlights ▶ Watch the Game ▶ Listen to the Game ▶

WAS SELECT: ALL ACTIVE 5

PLAYER NAME	PTS	REB	AST	F
<input type="checkbox"/> Daniels, Antonio	7	2	8	0
<input checked="" type="checkbox"/> Stevenson, DeSha	11	3	4	2
<input checked="" type="checkbox"/> Jamison, Antawn	18	10	0	3
<input checked="" type="checkbox"/> Butler, Coron	14	3	1	3
<input checked="" type="checkbox"/> Haywood, Brenda	12	5	0	3
<input type="checkbox"/> Blatche, Andray	3	5	0	3
<input checked="" type="checkbox"/> Mason, Roger	3	1	1	5
<input type="checkbox"/> Songaila, Darius	2	1	1	2
<input type="checkbox"/> Young, Nick	2	0	0	0
<input type="checkbox"/> Pecherou, Oleksiy	0	1	0	0
<input type="checkbox"/> Arenas, Gilbert				
<input type="checkbox"/> McGuire, Dominic				

BOS SELECT: ALL ACTIVE 5

PLAYER NAME	PTS	REB	AST	F
<input type="checkbox"/> Rondo, Rajon	4	2	2	2
<input checked="" type="checkbox"/> Allen, Ray	16	6	3	2
<input checked="" type="checkbox"/> Garnett, Kevin	21	6	6	3
<input checked="" type="checkbox"/> Pierce, Paul	16	4	2	3
<input type="checkbox"/> Perkins, Kendrick	9	3	1	3
<input checked="" type="checkbox"/> House, Eddie	5	6	3	1
<input type="checkbox"/> Allen, Tony	4	4	0	0
<input type="checkbox"/> Davis, Glen	1	0	0	2
<input checked="" type="checkbox"/> Posey, James	3	2	0	2
<input type="checkbox"/> Pollard, Scot				
<input type="checkbox"/> Scalabrine, Brian				
<input type="checkbox"/> Powe, Leon				

TD Banknorth GARDEN

WIZARDS **CELTICS**

WAS show: made shots missed shots **BOS** show: made shots missed shots

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(from "The Visual Display of Quantitative Information," Tufte 1983.)

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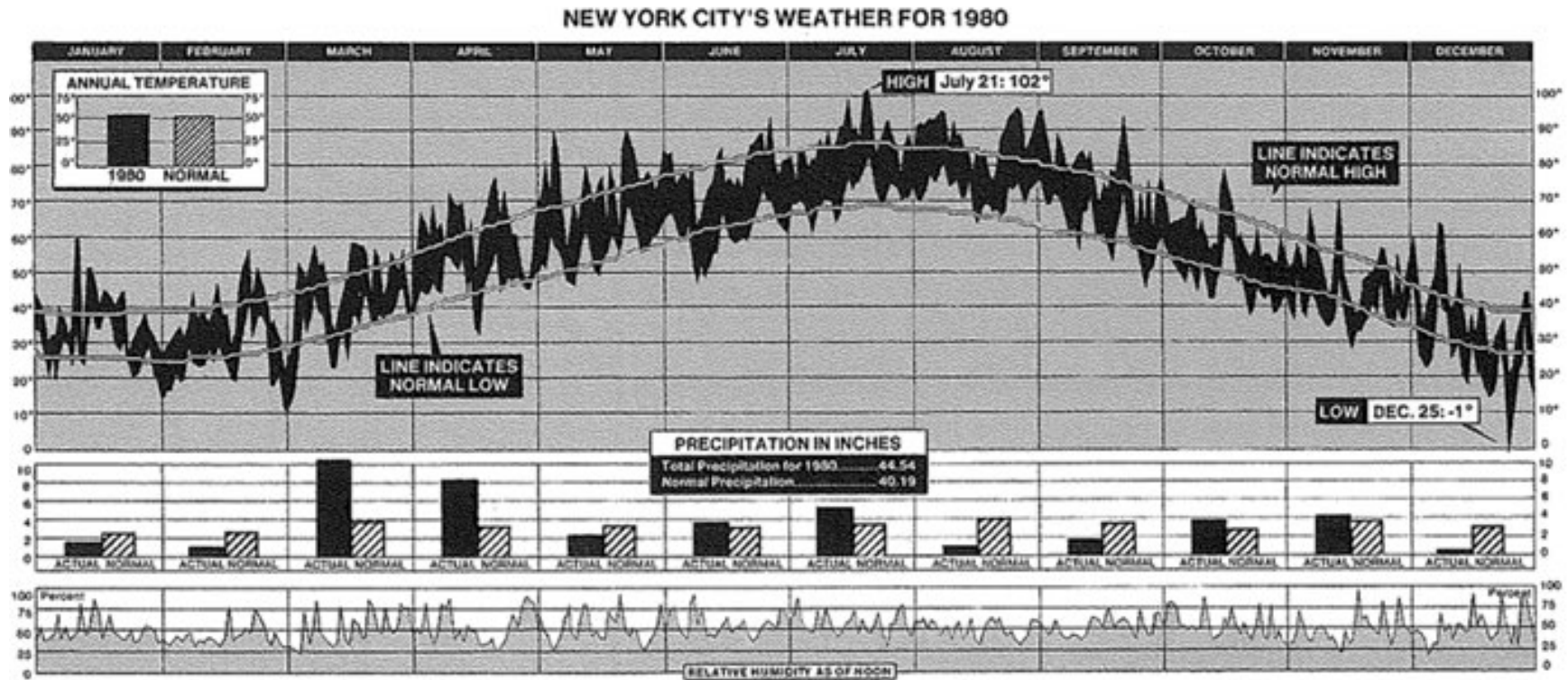
Data-ink Ratio

Multi-functioning
graphical elements

Data density

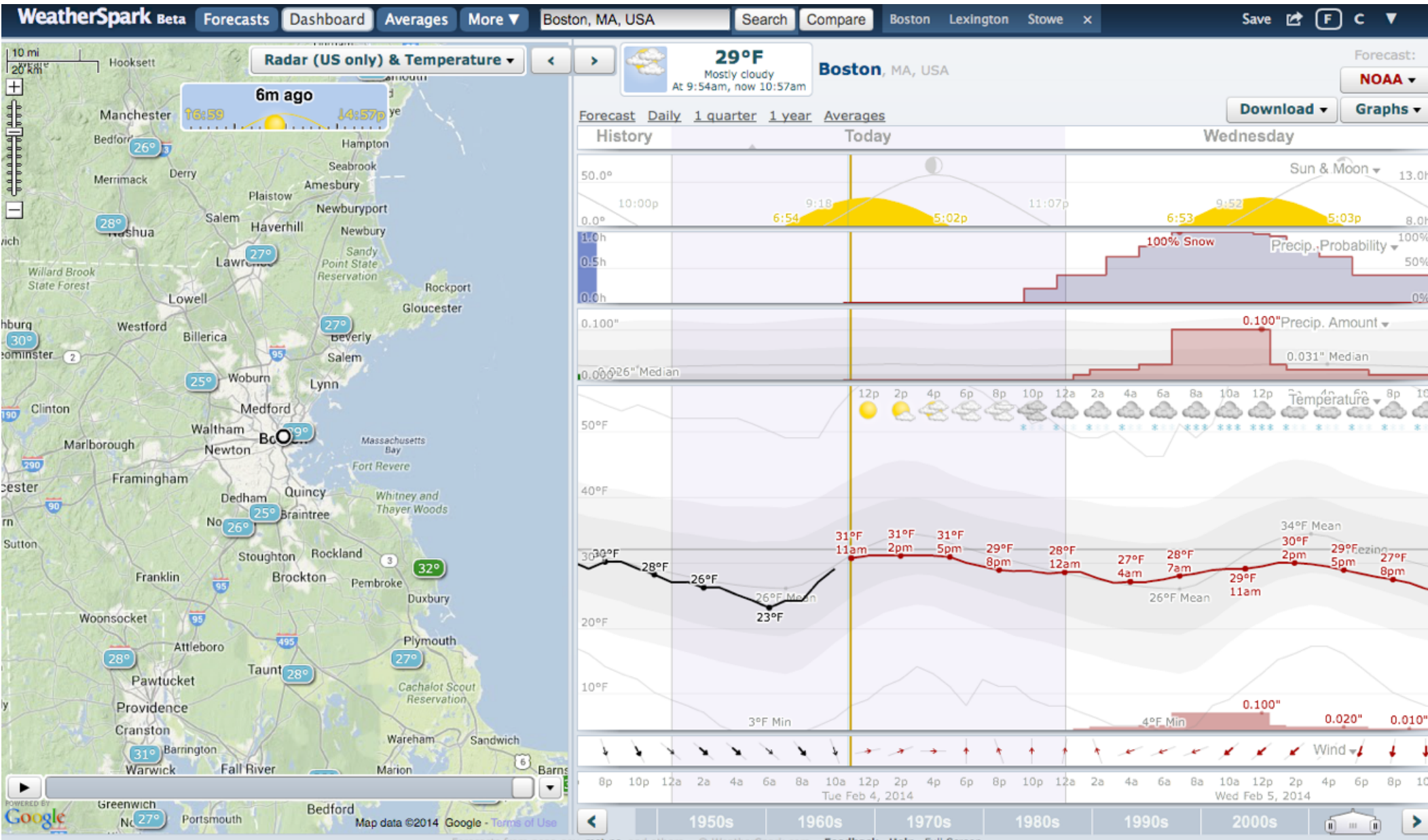
Small multiples

Data density



New York Times, January 11, 1981, p. 32.

Data (over?) density



<http://weatherspark.com/#!dashboard;a=USA/MA/Boston>

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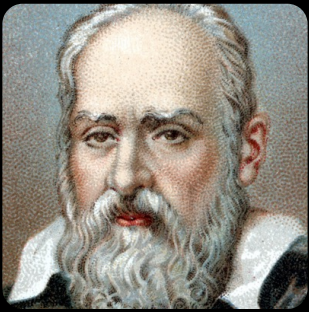
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Small multiples



GALILEO GALILEI

(1564-1642)

Small multiples

Scipio Principe.

Galileo Galilei, Familii. Servo della Ser. V. inuigilato
 no amidiuano, et de ogni spirito fu bene no solo satisfatto
 aliaro che non della stessa di Mathematici nella sua
 Via di Padova,

Diuere diuere determinate di presentare al Scipio Principe
 l'Uchiale et di figure di firmamento inanimabile di ogni
 regio et in terra marittima o terrestre sino di tenere per
 de nuovo artificio ne l'ingegno per se et ubi a disposizione
 di i. ser. L'Uchiale auato dalle piu di dite speculazioni di
 bro, potua in l'quantaggio di scipio Legni et Vole dell' inuigilato
 di i. ser. et pu. si ubi prima di, et supra noi et distinguere
 di numero et la qualita dei Vasselli quidiare la sua forza
 balla in alla caccia al amiatimento o alla fuga, o pure a
 nella la pugna aperta in esse et particolarmente distinguere ogni suo
 mo et propriamente.

Apr. 7. di gennaio
 Giove si vede in i. ser. * * * * *

Apr. 8. di * * * * *

Apr. 12. di * * * * *

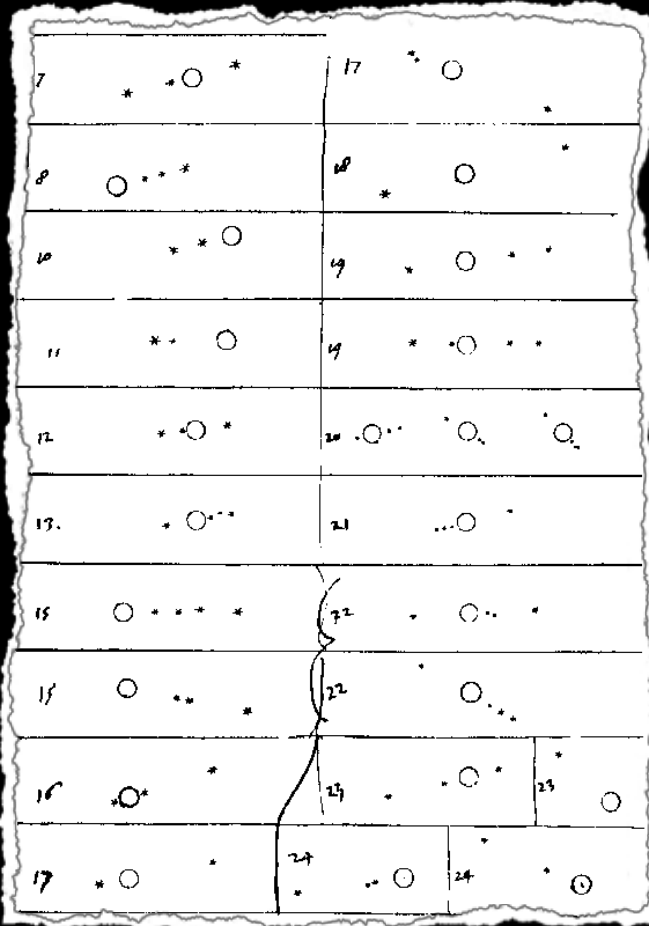
Apr. 13. di * * * * *

Apr. 14. di * * * * *

Apr. 15. di * * * * *

Apr. 16. di * * * * *

Apr. 17. di * * * * *



On the third, at the seventh hour, the stars were arranged in this
 quence. The eastern one was 1 minute, 30 seconds from Jupiter,
 closest western one 2 minutes; and the other western one was
 3 minutes removed from this one. They were absolutely on the
 same straight line and of equal magnitude.

On the fourth, at the second hour, there were four stars around
 Jupiter, two to the east and two to the west, and arranged precisely
 in a straight line, as in the adjoining figure. The easternmost was
 distant 3 minutes from the next one, while this one was 40 seconds
 from Jupiter; Jupiter was 4 minutes from the nearest western one
 and this one 6 minutes from the westernmost one. Their magnitude
 were nearly equal; the one closest to Jupiter appeared a little smaller
 than the rest. But at the seventh hour the eastern stars were only
 30 seconds apart. Jupiter was 2 minutes from the nearer eastern
 one, while he was 4 minutes from the next western one, and this
 one was 3 minutes from the westernmost one. They were all equal
 and extended on the same straight line along the ecliptic.

On the fifth, the sky was cloudy.




















On the sixth, only two stars appeared flanking Jupiter, as is seen
 in the adjoining figure. The eastern one was 2 minutes and the
 western one 3 minutes from Jupiter. They were on the same straight
 line with Jupiter and equal in magnitude.

On the seventh, two stars stood near Jupiter, both to the east



COMPOSITE TABLE*

*how AG met ET, 1995

Table 1: Summary of VLA NH₃ Observations in Low-Mass Dense Cores as of 1994
(double-boxed sources to be observed in this proposal)

Source	Central Source	Outflow	Year of Obs'n.	Relationship of VLA NH ₃ to Central Source	Comments (all observations are by the current proposers, unless otherwise indicated)
L1172	★		1984		
L1551	★		1989		Torrelles et al. 1985.
L1152	★	 *	1988		improve sensitivity and extend map with proposed observations
TMC-1A (≡ L1534)	★		1988		improve sensitivity with proposed observations
B335	★		1990		Keene, Menten & Masson, in prep.
L1689N	NO	NO	1985		Wooten and Loren 1987. Star shown at left (w/outflow) not within primary beam of observation.
AQ13	NO	?	1988		noise higher in on-line channels, suggestive of signal
B217	NO	NO	1983		relatively poor sensitivity
L1582	★	?	1984		
L1498	NO	NO	1984		
B5	★		1985		relatively poor sensitivity
B1	★		1988		relatively poor sensitivity

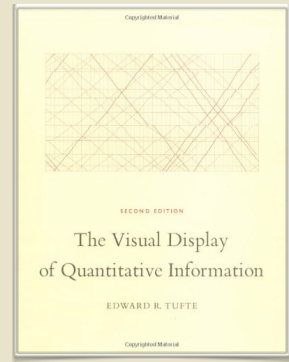
New Sources to be Observed in this Proposal

L1527	★		1995		infall candidate
L483	★		1995		infall candidate
B133	NO	NO	1995		strong extended sub-mm continuum, no known point source

*determination is unclear from existing data

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